



वार्षिक रिपोर्ट  
Annual Report  
2016 - 2017



भारत सरकार  
अन्तरिक्ष विभाग



GOVERNMENT OF INDIA  
DEPARTMENT OF SPACE

**वार्षिक रिपोर्ट**  
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## Citizens' Charter Of Department Of Space

Department of Space (DOS) has the primary responsibility of promoting the development of space science, technology and applications towards achieving self-reliance and facilitating in all round development of the nation. With this basic objective, DOS has evolved the following programmes:

- Indian National Satellite (INSAT) programme for telecommunication, television broadcasting, meteorology, developmental education, societal applications such as telemedicine, tele-education, tele-advisories and similar such services
- Indian Remote Sensing (IRS) satellite programme for the management of natural resources and various developmental projects across the country using space based imagery
- Indigenous capability for the design and development of satellite and associated technologies for communications, navigation, remote sensing and space sciences
- Design and development of launch vehicles for access to space and orbiting INSAT / GSAT, IRS and IRNSS satellites and space science missions
- Research and development in space sciences and technologies as well as application programmes for national development

### **The Department of Space is committed to:**

- Carrying out research and development in satellite and launch vehicle technology with a goal to achieve total self reliance
- Provide national space infrastructure for telecommunications and broadcasting needs of the country
- Provide satellite services required for weather forecasting, monitoring, etc.
- Provide satellite imagery required for the natural resources survey, management of natural disasters, public good services and monitoring of environment in the country
- Provide satellite imagery and specific products and services required for the application of space science and technology for developmental purposes through Central Government, State Governments, Quasi Governmental Organisations, Non-Government Organisations (NGOs) and the private sectors
- Undertake proof of concept demonstration of space applications
- Promote research in space sciences and development of applications programmes as per national needs

### **While implementing the above objectives, the Department of Space will:**


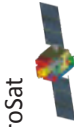

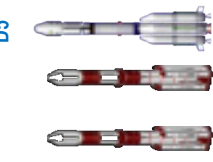
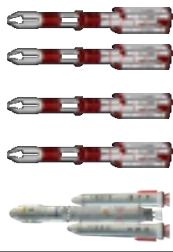
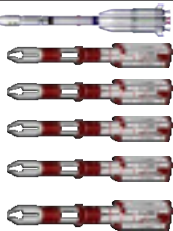
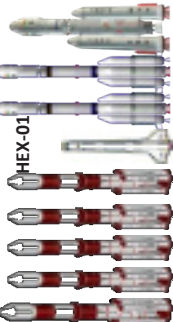
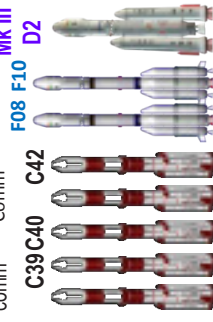

- Provide the required satellite transponders and facilities to meet the communications, television broadcasting and security requirements of our country
- Provide adequate earth observation capability in various spectral, spatial and temporal domains
- Provide launch services to meet national requirements and commercial needs
- Provide its products and services in a prompt and efficient manner to all the users / clients



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# SPACE MISSIONS 2013 -2018

MISSIONS	2013-14	2014-15	2015-16	2016-17	2017-18
<b>EARTH OBSERVATION SATELLITES</b>				CARTOSAT-2 Series1 CARTOSAT-2 Series2 RESOURCESAT-2A SCATSAT-1 INSAT-3DR	CARTOSAT-2 Series 3
<b>COMMUNICATION &amp; NAVIGATION SATELLITES</b>	IRNSS-1A GSAT-14 INSAT-3D GSAT-7	IRNSS-1B IRNSS-1C IRNSS-1D GSAT-16	IRNSS-1E IRNSS-1F GSAT-6 GSAT-15	GSAT-9 GSAT-19 IRNSS-1G GSAT-18	IRNSS-1H IRNSS-1I GSAT-20 GSAT-11 GSAT-17
<b>Procured Launch Service</b> <b>SPACE SCIENCE &amp; PLANETARY EXPLORATION SATELLITES</b>	Mars Orbiter Spacecraft 		AstroSat 		Chandrayaan-II 
<b>TECHNOLOGY DEVELOPMENT LAUNCH VEHICLES</b>	C22 C25 D5 	CARE C23 C24 C27 C26 Commercial Mk III-X 	C28C29 Commercial C30 C31 D6 	RLV-TD SCRAMJET C33 C34 C35 C36 C37 F05 F09 Mk III D1 HEX-01 	C38 comm C39 C40 C42 C41 Comm F08 F10 Mk III D2 
PSLV GSLV GSLV-MkIII 					

## Highlights

February 2016 - January 2017 witnessed numerous achievements of the Indian Space Programme. Six launch vehicle missions were successfully accomplished that included five PSLVs and one GSLV (Mk II) from Satish Dhawan Space Centre SHAR, Sriharikota while the six ISRO satellites, four student satellites and 22 foreign satellites were launched by these missions. The six ISRO satellites included four earth observation satellites and two navigation satellites. India's communication satellite GSAT-18 was also successfully launched from French Guiana. The Polar Satellite Launch Vehicle (PSLV) had the unique distinction of launching 20 satellites in a single mission while also demonstrating its capability to place satellites in two different orbits in a single mission.

ISRO also demonstrated new technologies in the launch vehicle programme. The Reusable Launch Vehicle-Technology Demonstrator (RLV-TD) and SCRAMJET Engine Technology Demonstrator had their successful maiden test flights. This apart, the launch of Geosynchronous Satellite Launch Vehicle - Mark II (GSLV- Mk II) became the third consecutively successful launch of GSLV carrying the indigenous Cryogenic Upper Stage (CUS).

Mars Orbiter Mission (MOM) spacecraft of India completed two years in its orbit around Mars while AstroSat, India's multi-wavelength observatory, successfully completed one year in orbit.

Important events of the Indian space programme during the reporting period are highlighted in a chronological order as follows:

- On March 10, 2016, the sixth member of the Indian Regional Navigation Satellite System (IRNSS) constellation, IRNSS-1F, was successfully launched onboard PSLV-C32 into a sub-Geosynchronous Transfer Orbit (GTO).
- IRNSS-1G, the seventh and final member of the IRNSS Constellation, was successfully launched by PSLV-C33 into a sub GTO on April 28, 2016. With this, IRNSS constellation of seven satellites was fully deployed. Hon'ble Prime Minister of India, Mr. Narendra Modi, dedicated IRNSS to the Nation as 'NavIC' (Navigation with Indian Constellation).
- On May 23, 2016, the first flight test of India's RLV-TD was successfully conducted.
- PSLV successfully launched 20 satellites in a single mission (PSLV-C34) on June 22, 2016. It included India's Cartosat-2 Series Satellite as primary payload and two satellites from Indian academia, namely, SWAYAM and SATHYABAMASAT and 17 satellites with a total weight of 555 kg for foreign customers from Canada, Germany, Indonesia and USA as co-passengers.
- On August 28, 2016, ISRO's SCRAMJET engine technology demonstrator was successfully flight tested.



- INSAT-3DR, India's weather satellite, was successfully launched into the planned GTO by the 10th flight of GSLV (GSLV-F05) on September 08, 2016.
- India's Mars Orbiter Spacecraft, that was earlier launched by PSLV-C25, successfully completed two years in its orbit on September 24, 2016.
- SCATSAT-1, a unique scatterometer mission, with a focus on weather forecasting services and seven co-passenger satellites were successfully launched into two different orbits in the same mission by PSLV-C35.
- AstroSat, India's first multi-wavelength observatory, launched earlier, successfully completed one year in orbit on September 28, 2016.
- India's communication satellite GSAT-18 was launched into a GTO by the European Ariane-5 VA231 from Kourou, French Guiana on October 06, 2016.
- Resourcesat-2A, equipped with a three tier imaging system for resource survey, was successfully launched into a polar SSO of 824 km by PSLV-C36 on December 07, 2016.

By January 2017, ISRO had a constellation of exclusive Meteorological satellites, Earth Observation satellites, Navigation Satellites, a multi-wavelength astronomical observatory, a spacecraft orbiting planet Mars and several commercial Communication satellites.

*During the reporting period, ISRO could accomplish 15 missions.*

## Launch Vehicle Programme

PSLV, the Indian operational launcher, completed its thirty-eighth launch (PSLV-C36) during the year. It was the thirty-seventh consecutive successful mission, proving the reliability of this vehicle in its class.

GSLV (Mk-II), equipped with the indigenous Cryogenic Upper Stage (CUS), successfully launched the country's latest weather satellite, INSAT-3DR, on September 08, 2016. This mission (GSLV-F05) further demonstrated the reliability of CUS engine and stage developed by ISRO. This was the fourth flight of GSLV to use the indigenous CUS.

GSLV-Mk III launch vehicle, capable of launching four-ton class of satellites into GTO, also progressed well with the development of high thrust CE 20 cryogenic engine and integration of C25 stage.

This apart, research and development activities as part of the Advanced Launch Vehicle Technology initiatives got a boost through the successful testing of RLV-TD and SCRAMJET engine technology demonstrator during the year. Besides, developmental efforts on semi-cryogenic engine are also being pursued for further enhancing the country's launch capability. Development of critical technologies for undertaking human spaceflight has also made progress during the reporting period.



## Satellite Programme

Successful launch of IRNSS-1F and 1G, the sixth and seventh satellites of the IRNSS Constellation, onboard PSLV-C32 and PSLV-C33 during the year signifies the completion of IRNSS constellation, which was dedicated to the nation by Hon'ble Prime Minister of India. IRNSS satellites employ the standard I-1K structure with a power handling capability of around 1660 W and a lift-off mass of about 1,425 Kg. Like their five predecessors, both IRNSS-1F and 1G carry a navigation payload as well as a ranging payload. In Orbit Tests (IOT) of Navigation Payload, Ranging Payload and TT&C transponder of IRNSS-1F and 1G were successfully completed during the year and the satellites were cleared for Navigation activities.

The year also witnessed the indigenous launch of four earth observation satellites – Cartosat-2 Series Satellite, INSAT-3DR, SCATSAT-1 and Resourcesat-2A. Of these, Cartosat-2 Series Satellite weighing 727 kg was launched by PSLV-C34. India's weather satellite INSAT-3DR, a follow-on meteorological satellite to INSAT-3D, with a lift-off mass of 2211 kg and equipped with an imager, sounder, Data Relay Transponder and Search & Rescue payloads onboard, was launched by GSLV-F05. The 371 kg SCATSAT-1, carrying a Ku-band scatterometer, was launched onboard PSLV-C35. Resourcesat-2A, the 1,235 kg remote sensing satellite intended for resource survey, was launched by PSLV-C36.

Apart from these indigenously launched satellites, the 3,404 kg GSAT-18, India's communication satellite carrying a total of 48 transponders working in C, Extended C and Ku-bands, was launched onboard European Ariane-5 and later successfully taken to its geostationary orbital slot by firing its Liquid Apogee Motor in steps from Master Control Facility (MCF), Hassan.

The new satellites being built for meeting the country's future requirements include IRNSS-1H, and 1I, which are planned to be launched onboard PSLV, GSAT-9 and GSAT-19 communication satellites to be launched by GSLV-MkII and GSLV-MkIII respectively and GSAT-17 & GSAT-11 communication satellites planned to be launched through procured launches. In the domain of earth observation satellites, it is planned to design, develop and build Cartosat-2 Series and Cartosat-3 in the Cartosat series of satellites, Oceansat-3 in the Oceansat series, RISAT-1A in the Radar Imaging Satellite series and GISAT-1 in the INSAT series for meteorological applications.

## Space Science Programme

Mars Orbiter Mission (MOM), India's first inter-planetary mission, completed two years in its orbit around Mars. The health parameters of Mars Orbiter spacecraft are normal and all the five payloads are sending useful data. The Mars Colour Camera has produced more than 530 images so far, one of which has appeared on the cover page of the November 2016 issue of the National Geographic Magazine. The Archived data is now made public for free download and scientific research through ISRO's website. There were more than 175,000 hits and about 200 Gb data was downloaded. ISRO has also launched MOM Announcement of Opportunity (AO) programmers for researchers in the country to use MOM data for R&D. The success of Mars Orbiter Mission has motivated India's student and research community in a big way.



AstroSat, India's first multi-wavelength observatory, completed one year in orbit on September 28, 2016. An Announcement of Opportunity (AO) was made in June 2016 for Indian researchers to explore the universe using data from AstroSat. As part of one-year completion of AstroSat in orbit, a one-day workshop was organised at Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune on September 29, 2016, to highlight the technical and scientific achievements of this satellite. The first set of scientific results and the future scope of AstroSat were presented during the workshop.

The future space science missions of ISRO include Chandrayaan-2, a follow-on mission to Chandrayaan-1 with an Orbiter, Lander and Rover to explore the Moon, which is to be launched onboard GSLV and Aditya-L1, a scientific mission for solar studies carrying five payloads including a Coronagraph. Aditya-L1 is planned to be placed into a halo orbit around the L1 Lagrangian point.

### **Space Applications and Disaster Management Support**

The hallmark of Indian space programme has been the application-oriented efforts and the benefits that have accrued to the country through this programme. The societal services offered by INSAT / GSAT satellites in the area of tele-education and telemedicine were continued during the year. Remote Sensing applications projects at National, State and Local levels are being carried out through well-established multi-pronged implementation architecture of National Natural Resources Management System (NNRMS) in the country. During the year, Indian Remote Sensing Satellite constellation helped in Agricultural Crops Inventory, Agricultural Drought, Forest Fire, Landslides and Earthquake Monitoring, Gas pipeline monitoring, Groundwater Prospects Mapping, Inventory, Monitoring of Glacial Lakes / Water Bodies and Satellite Aided Search & Rescue.

The Disaster Management Support (DMS) Programme of ISRO is continuing to provide space based data and information as well as communication means for the efficient management of disasters. The Decision Support Centre (DMS-DSC) established at National Remote Sensing Centre (NRSC) is engaged in monitoring natural disasters such as floods, cyclones, landslides, earthquakes and forest fires. The major calamities faced by the country in 2016 were the wide spread floods in 11 states and a major forest fire in Uttarakhand State. During 2016, major floods in Assam, Bihar, Uttar Pradesh, Madhya Pradesh, West Bengal, Odisha, Andhra Pradesh, Rajasthan, Arunachal Pradesh, Maharashtra and Manipur were monitored in near real-time. Monitoring and mapping of these floods was carried out and more than 110 flood maps were disseminated to the concerned State and Central officers in addition to making them available to users on the web through Bhuvan and NDEM web portals.

The depressions formed in the Bay of Bengal including the cyclonic storms Roanu in May, Kyant in October and Vardah in December 2016 were monitored and the cyclone track and intensity were predicted. All the information was regularly updated on the MOSDAC website as part of information dissemination.

In 2016 fire season, many fire locations were generated using satellite data. Near real time observations were provided to the Ministry of Home Affairs and the Uttarakhand State Government for addressing



the forest fire episodes that occurred in Uttarakhand in 2016. Value added active fire locations are disseminated through Bhuvan. At the international level, ISRO supported 23 disaster events in 10 countries by providing 42 data sets from IRS satellites in 2016.

## Space Commerce

Antrix Corporation, the commercial arm of the Department of Space, is marketing the Indian space products and services in the global market. Under commercial contracts with Antrix, 79 international customer satellites have been successfully launched by PSLV during 1999-2016 period. During 2016, PSLV successfully launched 22 satellites from abroad. Proposals from International Customers for the launch of their satellites onboard PSLV are under discussion and consideration.

## Indian Space Industry

Involvement of Indian space industry continued during the year. In the past, it has made significant contribution towards the realisation of subsystems required for the Indian space programme. Department of Space has been associated with more than 500 small, medium and large-scale industries while implementing various programmes. So far, the Department of Space has transferred about 300 technologies to Indian Industries for commercialisation and undertaken technical consultancies in various fields.

## International Cooperation

International cooperation is an integral part of Indian space activities and ISRO continues to lay importance on bilateral and multilateral relations with space agencies and space related bodies with the aim of taking up new scientific and technological challenges, defining international frameworks for exploitation and utilisation of outer space for peaceful purposes, refining space policies and building and strengthening existing ties between the countries. During the year, ISRO signed cooperative agreements with the French, UAE, Japanese, US, Vietnamese, Afghanistan and Russian space agencies as well the US Geological Survey.

## Human Resources

The achievements of Indian space programme are the result of commitment, dedication and expertise of its personnel who continue to play a key role. Recognising the importance of talented and motivated personnel, the department has laid stress on recruitment, training and career progression features. The Department of Space continues to strive for providing its personnel with facilities such as housing, medical, canteen and schooling for their children. The total approved sanctioned strength of the department as on March 01, 2016 is 16,902, out of which 12,300 are in Scientific and Technical (S&T) category and 4,602 are under administrative category.



### **Indian Institute of Space Science and Technology**

Towards capacity building in human resources and to meet the growing demands of the Indian Space Programme, the Indian Institute of Space Science and Technology (IIST), a deemed University, was established at Thiruvananthapuram in 2007. In the fulfillment of its primary objective of providing quality manpower to ISRO, 96 B. Tech graduates from IIST were placed as Scientists / Engineers at various centres of ISRO in 2016.

### **Public Awareness on Space Programme**

During the year, ISRO organised media visits to SDSC SHAR, Sriharikota for the live coverage of PSLV and GSLV launches. Besides, ISRO also organised many exhibitions at National and International Conferences, important public congregations like cultural festivals, trade fairs and events and also at academic institutions. Exhibitions and other outreach events were also organised in association with Non-Governmental Organisations in various places for keeping the public abreast of the Indian space programme.

### **Right to Information – Ensuring Transparency**

Strict compliance with the requirements of Right To Information (RTI) Act 2005 is practiced in the department. The Department of Space has implemented RTI Act 2005 by identifying the Central Public Information Officers, Assistant Public Information Officers and the Appellate Authority for stage one appeals. As required under the Act, the Department of Space has published the requisite information on DOS website (<http://www.dos.gov.in>) and on ISRO website (<http://www.isro.gov.in>). During the period January to December 2016, 882 applications were received and information was disseminated under the provisions of the RTI Act. 130 appeals were received by the First Appellate Authority and eight appellants approached the Second Appellate Authority, namely, Central Information Commission.

### **Summary**

The Indian space programme during the year made good progress in its quest towards mastering critical technologies and witnessed notable milestones in space exploration. Necessary infrastructure for casting large boosters, liquid propellant engines, heavy cryogenic boosters for advanced heavier launchers and missions in the area of remote sensing, communications and navigational satellites as well as space science have been established. The expansion of space applications programmes including disaster management support and outreach through Direct-To-Home television, reiterates the increasing role played by the Indian space systems in providing direct benefits to the society. Thus, the Indian Space Programme continues to pursue goals on several fronts in meeting its objective.



## Organisation

Space activities in the country were initiated with the setting up of Indian National Committee for Space Research (INCOSPAR) in 1962. In the same year, work on Thumba Equatorial Rocket Launching Station (TERLS) near Thiruvananthapuram was also started. Indian Space Research Organisation (ISRO) was established in August 1969. The Government of India constituted the Space Commission and established the Department of Space (DOS) in June 1972 and brought ISRO under DOS in September 1972.

Space Commission formulates the policies and oversees the implementation of the Indian space programme to promote the development and application of space science and technology for the socio-economic benefit of the country. DOS implements these programmes through, mainly, ISRO, Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), North Eastern-Space Applications Centre (NE-SAC) and Semi-Conductor Laboratory (SCL). Antrix Corporation, established in 1992 as a Government owned company, markets the space products and services.



**Antariksh Bhavan**

The establishment of space systems and their applications are coordinated by the national level committees, namely, INSAT Coordination Committee (ICC), Planning Committee on National Natural Resources Management System (PC-NNRMS) and Advisory Committee for Space Sciences (ADCOS).

DOS Secretariat and ISRO Headquarters are located at Antariksh Bhavan in Bengaluru. Programme offices at ISRO Headquarters coordinate the programmes like satellite communication, earth observation, navigation, launch vehicle, space science, disaster management support, sponsored research scheme, contracts management, international cooperation, system reliability and quality, safety, publications and public relations, budget and economic analysis and human resources development. The major establishments of DOS and their area of activities are given in the following paragraphs:

### **Vikram Sarabhai Space Centre (VSSC)**

Vikram Sarabhai Space Centre (VSSC) at Thiruvananthapuram is the lead centre of ISRO responsible for the design and development of launch vehicle technology. The Centre pursues active research and development in the fields of aeronautics, avionics, materials, mechanisms, vehicle integration, chemicals, propulsion, space ordnance, structures, space physics and systems reliability. The Centre undertakes crucial responsibilities of design, manufacturing, analysis, development and testing related to the realisation of subsystems for the different missions. These are sustained by activities towards programme





**Entrance to Veli Complex, VSSC**

planning and evaluation, technology transfer, industry coordination, human resources development and safety. Planning, execution and maintenance of all civil works related to the Centre is also carried out. The Centre depends on administrative and auxiliary services for support.

VSSC has extension Centres at Valiamala housing major facilities of mechanisms, vehicle integration and testing and at Vattiyookavu for the development of composites. The Ammonium Perchlorate Experimental Plant (APEP) has been set up by VSSC at Aluva near Kochi.

The major programmes at VSSC include Polar Satellite Launch Vehicle (PSLV), Geosynchronous Satellite Launch Vehicle (GSLV) and Rohini Sounding Rockets as well as the development of Geosynchronous Satellite Launch Vehicle (GSLV) Mk III, Reusable Launch Vehicles, advanced technology vehicles, air-breathing propulsion and critical technologies towards human spaceflight.

### **ISRO Satellite Centre (ISAC)**

ISRO Satellite Centre (ISAC), Bengaluru, is the lead centre for conceptualisation, design, development, fabrication, Integration and testing of complex satellite technology and is also actively engaged in the Research & Development in the area of advanced state of art technologies, total management of all satellite missions, creation of a vibrant space industry for realisation of space systems, technology transfer, academia interface, etc.



**A Test Facility at ISITE**

ISRO Satellite Integration and Test Establishment (ISITE) is equipped with state-of-the-art clean room facilities for spacecraft integration and test facilities including a 6.5 Metre thermo vacuum chamber, 29 Ton vibration facility, Compact Antenna Test Facility and acoustic test facility under one roof. Assembly, Integration and Testing of all Communication and Navigation Spacecraft is carried out at ISITE. A dedicated facility for the productionisation of standardised subsystems is established at ISITE.



The Centre has built 79 satellites from experimental satellites to the state-of-the-art operational satellites in the areas of communication, navigation, remote sensing and space science missions.

### **Satish Dhawan Space Centre (SDSC) SHAR**

Satish Dhawan Space Centre (SDSC) SHAR, Sriharikota, the Spaceport of India, is responsible for providing Launch Base Infrastructure for the Indian Space Programme. This Centre has the facilities for solid propellant processing, static testing of solid motors, launch vehicle integration and launch operations, range operations comprising telemetry, tracking and command network and mission control centre.

The Centre has two launch pads from where the rocket launching operations of PSLV and GSLV are carried out. The mandate for the centre is (i) to produce solid propellant boosters for the launch vehicle programmes of ISRO (ii) to provide the infrastructure for qualifying various subsystems and solid rocket motors and carrying out the necessary tests (iii) to provide launch base infrastructure for satellites and launch vehicles.

The Centre is realising a Second Vehicle Assembly Building (SVAB) facility for the integration of launch vehicles for meeting the future requirements for the Indian Space Programme. The main objectives of the SVAB are a) to meet increased launch frequency, b) to provide full-fledged integration facility for GSLV Mk-III flights, c) to take care of future launch vehicles, d) to implement Auxiliary Umbilical Tower concept to reduce launch pad occupancy time and e) to serve as a prime integration facility for future Third Launch Pad.

SDSC SHAR has a separate launch pad for launching sounding rockets. The centre also provides the necessary launch base infrastructure for sounding rockets of ISRO and for assembly, integration and launch of sounding rockets and payloads.

### **Liquid Propulsion Systems Centre (LPSC)**

Liquid Propulsion Systems Centre (LPSC) is the centre for design, development and realisation of liquid propulsion stages for ISRO's Launch Vehicles. Development of fluid control valves, transducers, propellant management devices for vacuum conditions and other key components of liquid propulsion systems are also under the purview of LPSC.

LPSC activities and facilities are spread across its two campuses namely, LPSC, Valiamala, Thiruvananthapuram and LPSC, Bengaluru, Karnataka.



**LPSC Main Building at Valiamala**



**LPSC, Valaimala** is responsible for R&D, System Design / Engineering and Project Management functions. The Fluid Control Components Entity and the Materials and Manufacturing Entities are located here apart from the Earth Storable and Cryogenic Propulsion Entities, handling the core tasks of the Centre.

**LPSC, Bengaluru** is responsible for design and realisation of propulsion systems for remote sensing and communication satellites and other scientific missions. Development and production of transducers and sensors are all undertaken here.

### ISRO Propulsion Complex (IPRC)

ISRO Propulsion Complex (IPRC), Mahendragiri is equipped with the state-of-the-art facilities necessary for realising the cutting edge propulsion technology products for the Indian space programme.

The activities carried out at IPRC, Mahendragiri are: assembly, integration and testing of earth storable propellant engines, cryogenic engines and stages for launch vehicles; high altitude testing of upper stage engines and spacecraft thrusters as well as testing of its sub systems; production and supply of cryogenic propellants for Indian cryogenic rocket programme, etc. A Semi-cryogenic Cold Flow Test facility (SCFT) has been established at IPRC, Mahendragiri for the development, qualification and acceptance testing of semi-cryogenic engine subsystems.



**Main Engine and Stage Test Facility  
at IPRC**

IPRC is responsible for the supply of Storable Liquid Propellants for ISRO's launch vehicles and satellite programmes. IPRC delivers quality products to meet the zero defect demand of ISRO space programme ensuring high standards of safety and reliability. It also carries out Research & Development (R&D) and Technology Development Programmes (TDP) towards continued improvement of its contribution to the Indian space programme.

### Space Applications Centre (SAC)

Space Applications Centre (SAC) at Ahmedabad is spread across two campuses having multi-disciplinary activities. The core competence of the Centre lies in development of space borne and air borne instruments / payloads and their applications for national development and societal benefits. These applications are in diverse areas and primarily meet the communication, navigation and remote sensing needs of the country. Besides these, the Centre also contributed significantly in scientific and planetary missions of ISRO like Chandrayaan-1, Mars Orbiter Mission, etc. The communication transponders developed at this Centre for Indian National Satellite (INSAT) and Geo Synchronous Satellite (GSAT) series of satellites are used by government and private sector for VSAT, DTH, Internet, broadcasting, telephones etc.



This centre also designs and develops the optical and microwave sensors for the satellites, signal and image processing software, GIS software and many applications for Earth Observation (EO) programme of ISRO. These applications are in diverse areas of Geosciences, Agriculture, Environment and Climate Change, Physical Oceanography, Biological Oceanography, Atmosphere, Cryosphere, Hydrosphere, etc. The facilities at SAC include highly sophisticated payload integration laboratories, electronic and mechanical fabrication facilities, environmental test facilities, systems reliability / assurance group, image processing and analysis facilities, project management support group and a well-stocked library. SAC has active collaborations with industry, academia, national and international institutes for research and development. The Centre also conducts nine-month post graduate diploma courses for students from the Asia Pacific region under the aegis of the Centre for Space Science and Technology Education (CSSTE-AP) in satellite meteorology and communication.

### **Development and Educational Communication Unit (DECU)**

The Development and Educational Communication Unit (DECU) at Ahmedabad, is dedicated for realising satellite communication based societal applications in the country. The major activities of DECU are – SATCOM networks configuration, implementation, upgradation, migration, utilisation, sustenance, social research and evaluation, Programme production and transmission and Training. It works with user agencies and experiments with innovative configurations to meet their requirements and facilitates in covering the 'last mile' in space applications to reach the unreached.

At present, the major programmes supporting development, education and training that are carried out by DECU include Telemedicine (TM), Tele-Education (TE), Projects resulted as an outcome of the national meet of space technology and tools, other SATCOM based development and applications.

### **ISRO Telemetry, Tracking and Command Network (ISTRAC)**

ISRO Telemetry, Tracking and Command Network (ISTRAC), Bengaluru is entrusted with the major responsibility to provide tracking support for all the satellite and launch vehicle missions of ISRO. The major objectives of the centre are: carrying out mission operations of all operational remote sensing and scientific satellites, providing Telemetry, Tracking and Command (TTC) services from launch vehicle lift-off till injection of satellite into orbit and to estimate its preliminary orbit in space and hardware and software developmental activities that enhance the capabilities of ISTRAC for providing flawless TTC and Mission Operations services.

Towards, these objectives, ISTRAC has established a network of ground stations at Bengaluru (BL1, BL2 & BL3, BL4), Lucknow (I and II), Mauritius (I and II), Sriharikota (SHAR I and II), Port Blair, Thiruvananthapuram, Brunei, Biak-1 and 2 (Indonesia) and the Deep Space Network Stations DSN-32 and DSN-18. The Mission Operations Complex (MOX) located at Bengaluru carries out round-the-clock mission operations for all remote sensing and science satellites. All network stations of ISTRAC are connected to MOX through dedicated high-performance satellite communication links and / or terrestrial communication links hired from PSTN. ISTRAC has established a network of stations to support IRNSS



satellites consisting of four IRCDR stations (Hassan, Bhopal, Jodhpur and Shillong), 15 IRIMS stations (Bengaluru, Hassan, Bhopal, Jodhpur, Shillong, Dehradun, Port Blair, Mahendragiri, Lucknow, Kolkata, Udaipur, Shadnagar and Pune). ISTRAC has also established the ISRO Navigation Centre, including an IRNWT facility at Bengaluru.

In keeping with its long-established TTC support responsibility, ISTRAC has also been mandated to provide space operations support for Deep Space Missions of ISRO, undertake development of radar systems for launch vehicle tracking and meteorological applications, establish and operationalise the ground segment for Indian Regional Navigational Satellite System, provide Search & Rescue and Disaster Management Services and support space based services like telemedicine, Village Resource Centre (VRC) and tele-education.

### **Master Control Facility (MCF)**

Master Control Facility (MCF) at Hassan in Karnataka and Bhopal in Madhya Pradesh monitors and controls all the Geostationary / Geosynchronous satellites of ISRO, namely, INSAT, GSAT, Kalpana and IRNSS series of satellites. MCF is responsible for Orbit Raising of satellites, In-orbit payload testing, and On-orbit operations all through the life of these satellites. MCF activities include round-the-clock Tracking, Telemetry & Commanding (TT&C) operations, and special operations like Eclipse management, Station-keeping manoeuvres and recovery actions in case of contingencies. MCF interacts with User Agencies for effective utilisation of the satellite payloads and to minimise the service disturbances during special operations.



**Satellite Control Earth Station with Full Motion Antennae at MCF, Bhopal**

MCF, Hassan currently controls 23 satellites. To carry out these operations effectively, MCF Hassan is having an integrated facility consisting of nine Satellite Control Earth Stations.



MCF at Bhopal completed its eleventh year of successful operations. The Facility is configured with three Satellite Control Earth Stations (SCES) consisting of Full Motion Antennae and Limited Motion Antennae, a Satellite Control Centre and a Power Complex. MCF Bhopal is currently managing round-the-clock operations of five satellites in close coordination with MCF Hassan.

### **ISRO Inertial Systems Unit (IISU)**

ISRO Inertial Systems Unit (IISU), Thiruvananthapuram is responsible for the design and development of Inertial Systems for Launch Vehicles and Spacecraft programmes of ISRO. Major systems like Inertial Navigation Systems based on mechanical gyros and optical gyros, Attitude Reference Systems, Rate Gyro Packages and Accelerometer Packages are developed indigenously and used in various missions of ISRO. IISU also designs and develops Actuators and Mechanisms for spacecraft and allied applications.

IISU has crossed major milestones of competence building phase, experimental phase and is presently engaged in the process of consolidation and productionisation of the Sensors, Systems, Actuators and Mechanisms for a variety of launch vehicle and spacecraft applications.

IISU is engaged in continuous Research and Development too. The experience and knowledge gained over the years are used for perfecting the present class of sensors and systems and developing new technologies. Further IISU has also initiated advanced technology development programs in niche areas to adapt itself as a Centre of Excellence in Inertial Sensors and Systems. IISU strives to make the systems cost effective, reliable and realisable in tune with global trends.

### **Laboratory for Electro-Optics Systems (LEOS)**

The Laboratory for Electro-Optics Systems (LEOS), Bengaluru is responsible for design, development and production of electro-optic sensors and optics for spacecraft use. Sensor system includes earth sensors, star sensors, sun sensors, magnetic sensors, fiber optic gyro, temperature sensors and processing electronics. Optics system includes optics for remote sensing cameras, radiometers, star sensor optics, optical filter, optical masks, optical coatings, IR detectors and MEMS based inclinometer. Research and development program by LEOS includes the development of miniature sensors, high accuracy Active Pixel Sensor, Miniature star tracker, Vision Sensors, Detectors, MEMS devices, Segmented Mirror Telescope optics and advanced optics for future spacecraft use.



**Optics Extension Block of LEOS**



# The Centres of Indian Space Programme

## CHANDIGARH

- Semi-Conductor Laboratory

## JODHPUR

- Western RRSC

## UDAIPUR

- Solar Observatory

## Mt. ABU

- Infrared Observatory

## AHMEDABAD

- Space Applications Centre
- Physical Research Laboratory
- Development and Educational Communication Unit

## MUMBAI

- ISRO Liaison Office

## BHOPAL

- Master Control Facility - B

## BENGALURU

- Space Commission
- Department of Space and ISRO Headquarters
- SCNP Office
- NNRMS Secretariat
- ADCOS Secretariat
- Civil Engineering Programme Office
- Antrix Corporation
- ISRO Satellite Centre
- Laboratory for Electro-Optics Systems
- ISRO Telemetry, Tracking and Command Network
- Southern RRSC
- Liquid Propulsion Systems Centre

## HASSAN

- Master Control Facility

## BYALALU

- Indian Deep Space Network
- Indian Space Science Data Centre
- ISRO Navigation Centre

## NEW DELHI

- DOS Branch Secretariat
- ISRO Branch Office
- Delhi Earth Station

## DEHRADUN

- Indian Institute of Remote Sensing
- Centre for Space Science and Technology Education in Asia-Pacific

## LUCKNOW

- ISTRAC Ground Station
- ISRO Navigation Centre

## SHILLONG

- North Eastern-Space Applications Centre

## KOLKATA

- Eastern RRSC

## NAGPUR

- Central RRSC

## HYDERABAD

- National Remote Sensing Centre

## SRIHARIKOTA

- Satish Dhawan Space Centre, SHAR

## TIRUPATI

- National Atmospheric Research Laboratory

## ALLUVA

- Ammonium Perchlorate Experimental Plant

## THIRUVANANTHAPURAM

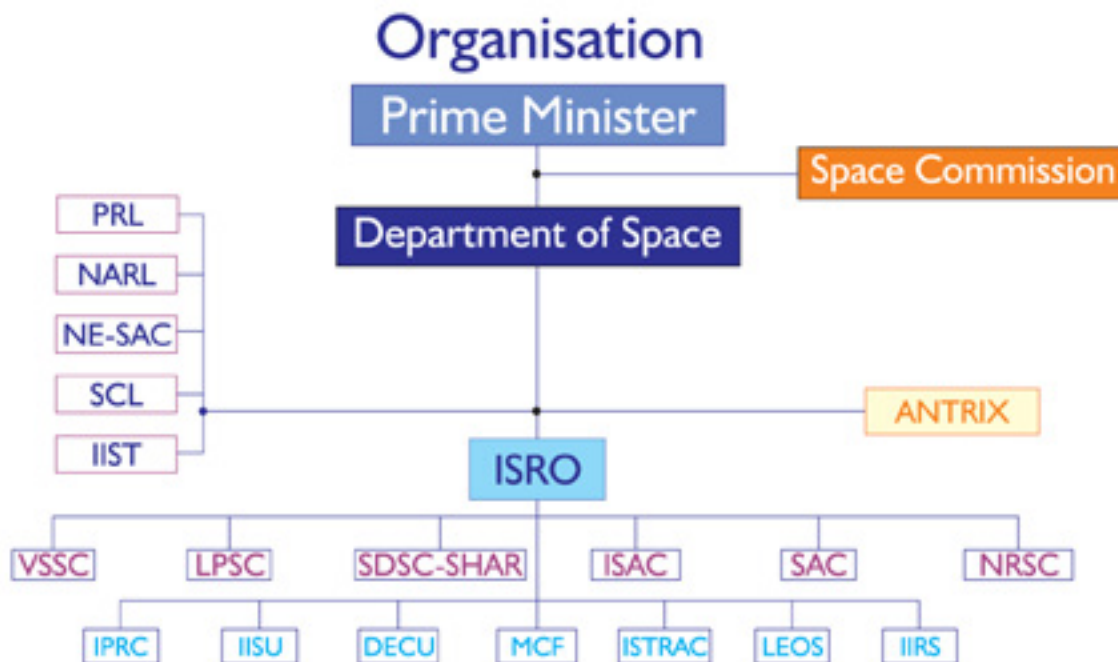
- Vikram Sarabhai Space Centre
- Liquid Propulsion Systems Centre
- ISRO Inertial Systems Unit
- Indian Institute of Space Science and Technology

## MAHENDRAGIRI

- ISRO Propulsion Complex

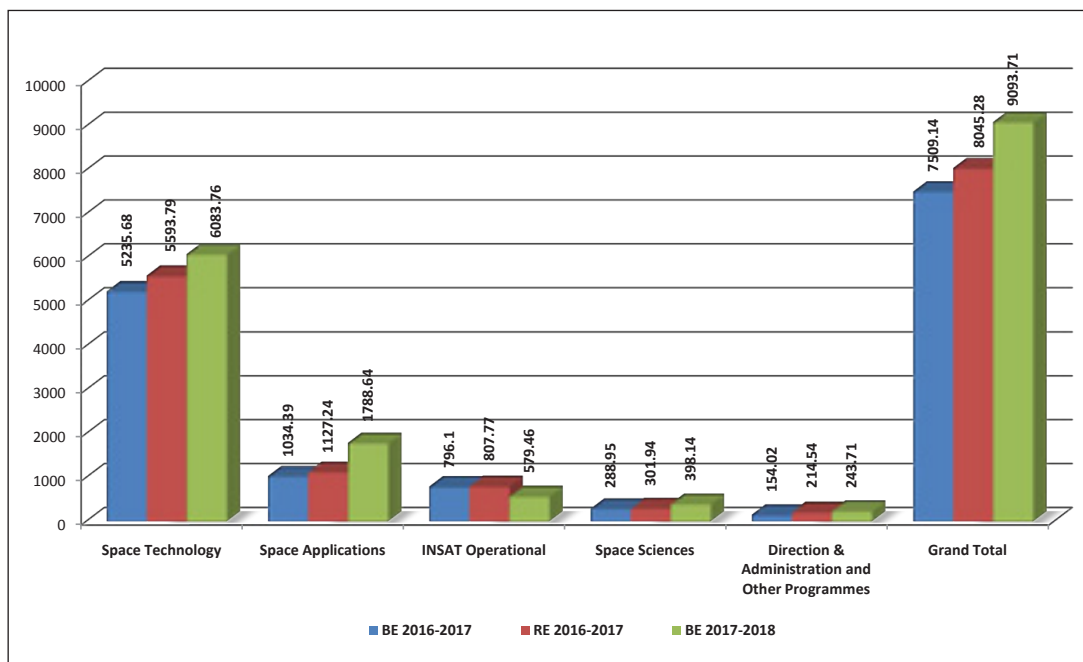
## PORT BLAIR

- Down Range Station



**PRL:** Physical Research Laboratory **NARL:** National Atmospheric Research Laboratory **NE-SAC:** North Eastern Space Applications Centre **SCL:** Semi-Conductor Laboratory **IIST:** Indian Institute of Space Science and Technology **ISRO:** Indian Space Research Organisation **Antrix:** Antrix Corporation Limited **VSSC:** Vikram Sarabhai Space Centre **LPSC:** Liquid Propulsion Systems Centre **IPRC:** ISRO Propulsion Complex **SDSC:** Satish Dhawan Space Centre **ISAC:** ISRO Satellite Centre **SAC:** Space Applications Centre **NRSC:** National Remote Sensing Centre **IISU:** ISRO Inertial Systems Unit **DECU:** Development and Educational Communication Unit **MCF:** Master Control Facility **ISTRAC:** ISRO Telemetry, Tracking and Command Network **LEOS:** Laboratory for Electro-optics Systems **IIRS:** Indian Institute of Remote Sensing

## Budget Profile (Rs. in Crores)



New facilities incorporated during 2016 includes installation of Two Axis Motion Simulator, CNC Milling Machine, 0.3 m Twin Thermovac in-house development, Seismometer Calibration Facility with Temperature Test Chamber, Vacuum Jacketed LN2 Transfer Lines, CNC Tool Room Lathe, DRUPS Power Supply and eight Channel Vibration controller.

### **National Remote Sensing Centre (NRSC)**

National Remote Sensing Centre (NRSC) at Hyderabad is responsible for remote sensing satellite data acquisition and processing, data dissemination, aerial remote sensing and decision support for disaster management. NRSC has a data reception station at Shadnagar near Hyderabad for acquiring data from Indian remote sensing satellites as well as others.



**NRSC Main Building at Hyderabad**

NRSC Ground station at Shadnagar acquires Earth Observation data from eleven Indian remote-sensing satellites Resourcesat-1, Resourcesat-2, Cartosat-1, Cartosat-2, Oceansat-2, RISAT-1, SARAL, Cartosat-2A, Cartosat-2B, Cartosat-2C and SCATSAT-1. Besides, data from different foreign satellites, namely, AQUA, TERRA, LANDSAT-7, LANDSAT-8, SNPP, NOAA-19 and METOP-A/B satellites is also being received, processed and archived. Presently, data acquired at AGEOS and SVALBARD stations is also being transferred to IMGEOs for level-0 processing, product generation, archival and dissemination. As part of the new MoU for the IGS, the IRS data acquired at these Ground stations are later sent to NRSC, Shadnagar for archival.

NRSC is also engaged in executing remote sensing application projects in collaboration with the users. The Aerial Services and Digital Mapping (ASDM) Area provides end-to-end Aerial Remote Sensing services and value-added solutions for various large scale applications like aerial photography and digital mapping, infrastructure planning, scanner surveys, aeromagnetic surveys, large scale base map, topographic and cadastral level mapping, etc.

Regional Remote Sensing Centres (RRSCs) support various remote sensing tasks specific to their regions as well as at the national level. RRSCs are carrying out application projects encompassing all the fields of natural resources like agriculture and soils, water resources, forestry, oceanography, geology, environment and urban planning. Apart from executing application projects, RRSCs are involved in software development, customisation and packaging specific to user requirements and conducting regular training programmes for users in geo-spatial technology, particularly digital image processing and Geographical Information System (GIS) applications.



### Indian Institute of Remote Sensing (IIRS)

Indian Institute of Remote Sensing (IIRS) at Dehradun is a premier institute with the objective of capacity building in Remote Sensing and Geo-informatics and their applications through education and training programmes at postgraduate level. The Institute also hosts and provides support to the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP), affiliated to the United Nations. The training and education programmes of the Institute are designed to meet the requirements of various target / user groups, i.e., for professionals at working, middle and supervisory levels, fresh graduates, researchers, academia, and decision makers. The duration of courses ranges from one week to two years.

### Physical Research Laboratory (PRL)

The Physical Research Laboratory (PRL), Ahmedabad is an autonomous unit of DOS and a premier research institute engaged in basic research in the areas of Astronomy and Astrophysics, Solar Physics, Planetary Science and Exploration, Space and Atmospheric Sciences, Geosciences, Theoretical Physics, Atomic, Molecular and Optical Physics and Astro-chemistry.



**PRL Main Campus, Ahmedabad**

PRL is actively participating in ISRO's planetary exploration programme and significant progress has been made in the areas of planetary sciences and exploration. Studies of stellar and solar astronomy are conducted from the Infra-red Observatory at Mt. Abu, and a lake site Solar Observatory in Udaipur, respectively. Another campus at Thaltej, Ahmedabad, hosts the planetary exploration (PLANEX) programme. Laboratory infrastructure has been established in this campus to develop instrumentation for future Space Science and Planetary missions and for initiating some of the proposed new research programmes. PRL is developing Alpha Particle X-ray Spectrometer (APXS) and Solar X-ray Monitor (XSM) for Chandrayaan-2 and Aditya Solar Wind Particle Experiment (ASPEX) for Aditya-L1 mission.

PRL has published nearly 200 papers in peer reviewed journals of both national and international standards during the year. Twenty Ph.D. theses were also submitted during the year.

### National Atmospheric Research Laboratory (NARL)

National Atmospheric Research Laboratory (NARL) at Gadanki near Tirupati, an autonomous society supported by DOS, is a centre for atmospheric research with the vision "Developing capability to predict the behaviour of the earth's atmosphere through observations and modeling". Towards realising this vision, NARL gives equal emphasis to technology development, observations, data archival, dissemination, assimilation and modeling.



NARL carries out its research activities under seven major groups, namely, Radar Application and Development Group, Ionospheric and Space Research Group, Atmospheric Structure and Dynamics Group, Cloud and Convective Systems Group, Aerosols, Radiation and Trace Gases Group, Weather and Climate Research Group and Computers and Data Management Group. Apart from these groups, there are also specific projects such as the LiDAR project and Advanced Space-borne Instrument Development project.



**MST Radar Facility at NARL**

### **North Eastern-Space Applications Centre (NE-SAC)**

North Eastern-Space Applications Centre (NE-SAC), located at Shillong, is a joint initiative of DOS and North Eastern Council (NEC) to provide developmental support to the North Eastern Region (NER) using space science and technology. The centre has the mandate to develop high technology infrastructure support to play the catalytic role in holistic development of NER of India by providing space science and technology support. The centre also coordinates with the State Remote Sensing Application Centres of NER and acts as a nodal centre for implementation of major national and regional programmes on natural resource management, infrastructure planning, healthcare, education, emergency communication, early warnings for disaster management support and atmospheric science research. The centre has completed a number of applications projects sponsored by the user agencies in the region and taken up research and development projects under Earth Observation Applications Mission, ISRO Geo-sphere Biosphere Programme, Satellite Communications, Disaster Management Support and Space Science Programmes.

### **Antrix Corporation Limited**

Antrix Corporation Limited (ACL), Bengaluru is a wholly owned Government of India Company under the administrative control of the Department of Space. Antrix Corporation Limited was incorporated as a private limited company owned by Government of India in September 1992 as a Marketing arm of ISRO for promotion and commercial exploitation of space products, technical consultancy services and transfer of technologies developed by ISRO. Another major objective is to facilitate development of space related industrial capabilities in India.

As the commercial and marketing arm of ISRO, Antrix is engaged in providing Space products and services to international customers worldwide. With fully equipped state-of-the-art facilities, Antrix provides end-to-end solution for many of the space products, ranging from supply of hardware and software including simple subsystems to a complex spacecraft, for varied applications covering communications, earth observation and scientific missions; space related services including remote sensing data service, Transponder lease service; Launch services through the operational launch vehicles (PSLV and GSLV); Mission support services; and a host of consultancy and training services.



### **Semi-Conductor Laboratory (SCL)**

Semi-Conductor Laboratory (SCL) at Chandigarh, an autonomous body under DOS, continued its efforts to create a strong Microelectronics base in the country and enhance capabilities in Very Large Scale Integrated circuit (VLSI) domain. Activities at SCL are focused on Design, Development, Assembly & Testing of Complementary Metal Oxide Semiconductor (CMOS) and Micro-Electro Mechanical Systems (MEMS) Devices for various applications. SCL is also engaged in manufacturing and supply of Application Specific Integrated Circuits (ASICs) for locomotives of Indian Railways, Hi-Rel board fabrication, component screening for ISRO units, indigenisation of electronics boards for Indian Air Force and production of Radiosonde for atmospheric studies.

Upgradation of SCL's Wafer Fab has been carried-out to acquire capabilities needed for the development of highly complex CMOS and Imaging devices. The Upgraded Wafer Fab has been successfully operationalised. Fabrication of four Multi-Product Wafer (MPW) lots has been completed having a total of 93 designs for ASICs / IPs / Test-Chips done in-house. These include 14-bit Pipeline Analog-to-Digital Converter (ADC) and CMOS Camera Configurator for Satellite Payload and Vikram Processor for Launch Vehicle. Five MPW lots having complex ASICs for IRNSS, 32-bit Microprocessor, ROIC for MCT Detector and CMOS Imager are being fabricated. Fabrication of Frame Transfer CCD Detector Device for Ocean Colour Monitor-3 (OCM-3) Satellite Payload and 12K Time Delay Integration CCD Device for Remote Sensing Payload has been successful. Acoustic Sensor for Launch Vehicle and MEMS Cantilevers have been realised at SCL.

### **Indian Institute of Space Science and Technology (IIST)**

Indian Institute of Space Science and Technology (IIST), Asia's first Space University, was established at Thiruvananthapuram in 2007 with the objective of offering high quality education in space science and technology to meet the demands of Indian Space Programme. The institute offers undergraduate, postgraduate, doctoral and post-doctoral programmes in broad areas of space science, technology and applications. The institute is committed to excellence in teaching, learning and research. IIST fosters state-of-the-art research and development in space studies and provides a think-tank to explore new directions for the Indian Space Programme.

The Institute has faculty strength of nearly 100 spread across seven Departments. 139 undergraduates students and 92 postgraduate students were admitted for the academic year 2016-17. Also 51 research scholars were admitted during the current year.



# Communication and Navigation Satellite System

## COMMUNICATION SATELLITES

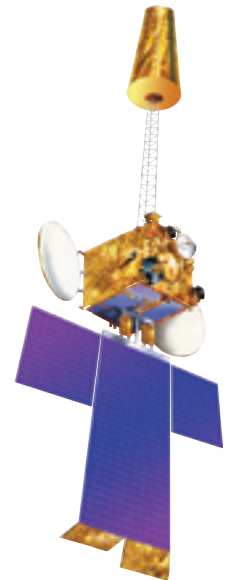
Indian National Satellite (INSAT) system, established in 1983, is one of the largest domestic communication satellite systems in the Asia Pacific Region with several communication satellites in operation: INSAT-3A, INSAT-3C, INSAT-4A, INSAT-4B, INSAT-4CR, GSAT-6, GSAT-8, GSAT-10, GSAT-12, GSAT-14, GSAT-16, GSAT-15 and GSAT-18. The overall coordination and management of INSAT system rests with INSAT coordination committee.

### Satellites in Service

#### INSAT-3A

INSAT-3A is a multipurpose satellite launched in April 2003. INSAT-3A payloads include Normal C-band transponders with expanded coverage from Middle East to South East Asia, Extended C-band transponders providing India coverage and Ku-band transponders providing India coverage.

The satellite also carries one Data Relay Transponder (DRT) and one Satellite Aided Search and Rescue (SAS&R) payload. SAS&R payload has a global receive coverage with 406 MHz uplink and C-band downlink with India coverage for the relay of signals from distress beacons in sea, air or land. The meteorological payloads of INSAT-3A are described in the chapter on "Earth Observation System".



INSAT-3A

#### INSAT-3C

Launched in January 2002, INSAT-3C payloads include Normal C-band transponders, Extended C-band transponders, S-band transponders to provide BSS services and an MSS payload. All the transponders provide coverage over India.

#### INSAT-4A

Launched in December 2005, INSAT-4A carries Ku-band transponders with footprint covering Indian mainland and C-band transponders with expanded coverage encompassing Indian geographical boundary and area beyond India.



### **INSAT-4B**

Configured with payloads similar to that of INSAT-4A, INSAT-4B was launched in March 2007. INSAT-4B carries Ku-band and C-band transponders. Two Transmit / Receive dual grid, offset, fed, shaped beam reflectors of 2.2 m diameter for Ku-band and 2 m diameter for C-band are used. INSAT-4B has augmented the high power transponder capacity over India in Ku-band and over a wider region in C-band. Due to a power anomaly, the satellite is operating at lower power.

### **INSAT-4CR**

INSAT-4CR launched in September 2007 carries high power Ku-band transponders. These transponders support Digital Satellite News Gathering (DSNG), Very Small Aperture Terminals (VSATs), Tele-education networks and other data communication services.

### **GSAT-8**

GSAT-8 is a communication satellite configured around 3,000 kg class (I-3K) bus with a lift-off mass of 3,093 kg and 6 kW power generation capacity with a mission life of more than 12 years. The satellite was launched in May 2011 and carries Ku-band commercial transponders as well as a two channel GAGAN (GPS Aided GEO Augmented Navigation) payload operating in L1 and L5 bands. The GAGAN payload provides Satellite Based Augmentation System (SBAS), through which the accuracy of the positioning information obtained from the GPS satellites is improved by a network of ground based receivers and made available to the users in the country through geostationary satellites.

### **GSAT-12**

GSAT-12 satellite is configured around 1,000 kg class (I-1K) bus with Extended C-band Solid State Power Amplifier (SSPA) based commercial transponders. The satellite was successfully launched onboard PSLV-C17 on July 15, 2011 with a lift-off mass of 1,410 kg. The satellite is designed for a mission life of 8 years.

### **GSAT-10**

GSAT-10, India's advanced communication satellite weighing 3,400 kg at lift-off, was successfully launched by Ariane-5 from Kourou, French Guyana on September 29, 2012. GSAT-10's commercial payload includes communication transponders in normal C-band, lower Extended C-band and Ku-band as well as a GAGAN payload operating in L1 and L5 bands. GSAT-10 is the second satellite to carry GAGAN payload after GSAT-8. GSAT-10 also carries a Ku-band beacon to help in accurately pointing ground antennas towards the satellite.



### GSAT-14

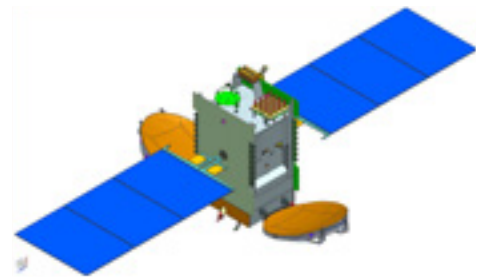
GSAT-14 payload is envisaged to enhance Extended C-band and Ku-band communication transponder capacity. It also carries Ka-band Beacons. Designed with a mission life of around 12 years, it employs the standard I-2K structure with the power handling capability of around 2600 W and a lift-off mass of 1,982 kg. GSAT-14 was successfully launched on January 05, 2014 onboard GSLV-D5 Mission, the second development flight of GSLV with indigenous Cryogenic Upper Stage.

### GSAT-16

GSAT-16 is a communication satellite configured around I-3K Extended bus with a lift off mass of 3,150 kg and 6500 W power generation capacity with mission life of more than 12 years. The spacecraft's commercial payload includes Transponders in Ku-band, C-band and Extended C-band. The satellite was launched by Ariane-5 from Kourou, French Guyana on December 06, 2014.

### GSAT-15

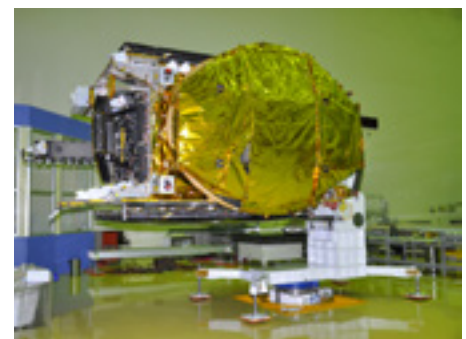
GSAT-15 is a communication satellite configured around I-3K bus with 3,164 kg lift-off mass and 6200 W power generation capacity. It is designed for a mission life of more than 12 years. The satellite's commercial payload includes Ku-Band transponders and a two channel GAGAN payload. The satellite was launched by Ariane-5 from Kourou, French Guyana on November 11, 2015.



GSAT-15

### GSAT-18

GSAT-18 is a communication satellite configured around I-3K extended bus with a lift-off mass of 3,404 Kg and 6 kW power generation capacity. The satellite carries Ku, Normal C and Extended C band transponders. It also carries Ku-band beacon to help in accurately pointing ground antennas towards the satellite. GSAT-18 is aimed at providing continuity to the communication services in the country and intended to replace INSAT satellites which will be reaching their end-of-mission-life. It is designed for a mission life of more than 15 years. The satellite was launched by Ariane-5 on October 06, 2016 from Kourou, French Guiana.



GSAT-18



## Satellites Under Development

### GSAT-17

GSAT-17 is a communication satellite configured around I-3K extended bus with a lift-off mass of about 3,425 kg and 6 kW power generation capacity. The satellite's commercial transponders include C, Lower Extended C-band and Upper Extended C transponders. The spacecraft also carries CxS and SxC MSS transponders as well as DRT & SAS&R payloads. Designed with a mission life of more than 15 years, the satellite is under advanced stage of realisation and is planned to be launched in the first half of 2017 by Ariane-5 launch vehicle.

### GSAT-19

GSAT-19 is planned as the payload for the first developmental flight of the indigenous GSLV-Mk III-D1 flight. It is a multi-beam satellite planned to carry Ka x Ku forward link transponders and Ku x Ka-band return link transponders. Designed for a mission life of 15 years, the satellite is in advanced stage of realisation and is planned to be launched during early 2017.

### GSAT-11

GSAT-11 is a multi beam high throughput communication satellite operating in Ka and Ku-bands employing a new I-6K bus platform. It provides 32 user beams in Ku-band and 8 hub beams in Ka band. The commercial payload includes Ka x Ku-Band Forward Link Transponders and Ku x Ka-band Return Link Transponders. The satellite is in advanced stage of realisation and is planned to be launched in the first half of 2017.

### GSAT-9

GSAT-9 satellite is configured to augment the Ku-band capacity. The satellite employs the standard I-2K structure with a power handling capability of around 3000 W, and a lift-off mass of 2,195 kg. It is designed for a mission life of more than 12 years. The subsystems of the satellite are in advanced stage of realisation and integration activities are in progress. The satellite is planned to be launched onboard GSLV-Mk II in the first half of 2017.



GSAT-9 Structure

## Satellite Navigation Programme

Satellite Navigation (SATNAV) has been identified as one of the important programmes of the department that includes activities such as GAGAN and Indian Regional Navigation Satellite System (IRNSS).

### GPS Aided Geo Augmented Navigation (GAGAN)

GAGAN is a joint project of Indian Space Research Organisation and Airports Authority of India.



The GAGAN Signal-In-Space (SIS) is available through GSAT-8, GSAT-10 and GSAT-15. GSAT-8 (PRN 127) and GSAT-10 (PRN 128) are transmitting GAGAN signals 24x7. The Directorate General of Civil Aviation (DGCA), India certified the GAGAN system to RNP0.1 (Required Navigation Performance, 0.1 Nautical Mile) service level on December 30, 2013 and later it was certified by DGCA for APV1.0 precision approach services over Indian Land Mass on April 21, 2015. With the certification of GAGAN for approach and landing operations, India has become the third country in the world to have such capabilities. GAGAN is the first SBAS system in the world to serve the equatorial region. The GAGAN system was dedicated to nation on July 13, 2015. The system is providing Satellite-based Navigation services with accuracy and integrity required for civil aviation applications and is also providing efficient air traffic management services over the Indian Airspace.

15 Indian Reference Stations (INRES), three Indian Navigation Land Uplink Stations (INLUS), two Indian Mission Control Centres (INMCC), and data communication links with redundancies have been established.

### Navigation Indian Constellation (NavIC)

NavIC is the Indian Regional Navigation Satellite System (IRNSS) developed by India. It is an independent system designed to provide accurate position information service to users in India as well as the region extending upto 1,500 km from its boundary, which is its primary service area. IRNSS is envisaged to provide two types of services, namely, Standard Positioning Service (SPS) and Restricted Service (RS) and provides a position accuracy of better than 20 m in the primary service area. The IRNSS system mainly consists of a Ground Segment, Space Segment and User Segment.

### Space Segment

The Space Segment consists of seven satellites with three in geostationary orbit and four in inclined geosynchronous orbit. The navigation payload transmits signals in L5 and S-band. The ranging payload consists of a C-band transponder which facilitates accurate determination of the range of the satellite.

IRNSS satellites employ the standard I-1K structure with a power handling capability of around 1660 W and a lift-off mass of around 1,425 Kg. All the seven satellites in the constellation have identical configuration and are operational after successful launch. The following table provides the launch dates of the seven navigation satellites.

Satellite	Launch Date
IRNSS-1A	Jul 01 2013
IRNSS-1B	Apr 04 2014
IRNSS-1C	Nov 10 2014
IRNSS-1D	Mar 28 2015
IRNSS-1E	Jan 20 2016
IRNSS-1F	Mar 10 2016
IRNSS-1G	Apr 28 2016



On the occasion of the launch of IRNSS-1G, Hon'ble Prime Minister of India dedicated IRNSS to the nation and named it as 'NavIC' - Navigation with Indian Constellation.



IRNSS-1G satellite enclosed within the two halves of PSLV-C33 Heat Shield

### IRNSS-1H & IRNSS-1I

IRNSS-1H and IRNSS-1I are two ground spare satellites planned to be realised as part of the approved project. Both IRNSS 1H and 1I satellites will have a configuration similar to the current IRNSS spacecraft bus and Navigation payload.

### Ground Segment

Ground Segment is responsible for the maintenance and operation of the IRNSS constellation. 15 IRNSS Range and Integrity Monitoring Stations (IRIMS), four IRNSS CDMA Ranging Stations (IRCDR), two IRNSS Spacecraft Control Facility (IRSCF), one IRNSS Network Timing Facility (IRNWT), one IRNSS Navigation Centre (INC) have been established. Additional IRIMS, IRNWT and INC are being established to provide adequate redundancies.

### User Segment

As has been the practice worldwide with other GNSS operators, DOS / ISRO has made available all the relevant information and details in the form of Interface Control Document (ICD) in public domain to enable the production of the user receivers. Besides, DOS / ISRO has been interacting with the manufacturers, system integrators and other stake holders to facilitate development and realisation of user devices and receivers. Different types of user receivers have been developed by ISRO and Industry. It is expected that more number of Indian vendors will participate in the production of the user receivers in the years to come as the adoption of NavIC among the users grows.



## Earth Observation System

Indian Earth Observation System operates in Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO), including associated ground segment to ensure data and services on a continued and assured basis. The Earth Observation (EO) Satellites have imaging capabilities in the visible, infrared, thermal and microwave regions of the electromagnetic spectrum, enabling the country in realising the major operational applications. The spatial resolutions range from 1 km to better than 1 m; temporal resolution from 22 days to 1 day and radiometric resolution ranging from 7 bit to 12 bit, has helped in versatile imaging capabilities.

### Earth Observation Satellites in Service

Starting with IRS-1A in 1988, ISRO has launched many operational remote sensing satellites into orbit. Currently, the remote sensing satellite constellation that are operational in orbit for developmental projects includes Resourcesat-2, Cartosat-1 & 2, Cartosat-2 Series, RISAT-1, Oceansat-2, Megha-Tropiques, SARAL, SCATSAT-1 and Resourcesat-2A. Though Cartosat-1, Cartosat-2 and Oceansat-2 satellites have completed their designed mission life in orbit, these satellites continue to provide imaging services for the remote sensing user community. The INSAT series of satellites, with meteorological payloads, operating from geostationary orbit, provide data for generating various parameters, namely, cloud motion vectors, cloud top temperature, water vapour content, vertical profiles of temperature, humidity and facilitate weather forecasting, genesis of cyclones and their track prediction, etc. Currently, INSAT-3A, KALPANA-1, INSAT-3D and INSAT-3DR are providing meteorological data to the user community. The details of the earth observation satellites in service are provided in the following table.

### Earth Observation Satellites in Service

SI No	Satellite	Launch Date and (Launch Vehicle)	Payload Specifications	Applications
1	Cartosat-1	May 5, 2005 (PSLV-C6)	Two Panchromatic Cameras, PAN (Fore) and PAN (Aft) with Spatial resolution: 2.5 m Swath: 30 km (Fore) & 27 km (Aft)	Cartographic applications like mapping, urban and rural infrastructure development and management as well as application in Land Information System (LIS) and Geographical Information System (GIS), and DEM generation
2	Cartosat-2	January 10, 2007 (PSLV-C7)	One Panchromatic Camera, PAN with Spatial resolution: 1 m Swath: 9.6 km	



SI No	Satellite	Launch Date and (Launch Vehicle)	Payload Specifications	Applications
3	Oceansat-2	September 23, 2009 (PSLV-C14)	Ocean Colour Monitor (8 Bands), 360 m & 1 km Spatial resolutions with 1,420 km swath, Ku-band Pencil beam Scatterometer and Radio Occultation Sounder (ROSA)	Ocean and atmospheric studies (like atmospheric humidity and temperature vertical profiles from ROSA)
4	Resourcesat-2	April 20, 2011 (PSLV-C16)	LISS-III: 4 Bands, 23.5 m resolution, 141 km swath LISS-IV: 3 Bands, 5.8 m resolution, 23 km Mx, 70 km Mx / Mono swath AWiFS: 4 Bands, 56 m resolution, 700 km swath	Resource Monitoring applications
5	Megha-Tropiques	October 12, 2011 (PSLV-C18)	Low Inclination orbit mission carrying MADRAS, SAPHIR (6 Channel humidity sounder with 2200 km swath), SCARAB (4 Channel Scanner for Radiation Budget with 2200 km swath) and GPS-ROS for radio occultation	Meteorological and Oceanographic applications
6	RISAT-1	April 26, 2012 (PSLV-C19)	C-band (5.35 GHz) SAR operating in various modes namely, 1. Fine Resolution Stripmap (FRS-1) 2. Fine Resolution Stripmap (FRS-2) 3. Medium Resolution ScanSAR (MRS) 4.Coarse Resolution ScanSAR (CRS)	Agriculture mapping, disaster management support activities



SI No	Satellite	Launch Date and (Launch Vehicle)	Payload Specifications	Applications
7	SARAL	February 25, 2013 (PSLV-C20)	Ka-band (35.75 GHz) Altimeter ARGOS Data Collection system	Ocean applications
8	Cartosat-2 Series Satellite	June 22, 2016 (PSLV-C34)	The satellite is similar to Cartosat-2, 2A and 2B	
9	Resourcesat-2A	December 07, 2016 (PSLV-C36)	LISS-III: 4 Bands, 23.5 m resolution, 141 km swath LISS-IV: 3 Bands, 5.8 m resolution, 70 km swath AWiFS: 4 Bands, 56 m resolution, 740 km swath	Resource Monitoring applications

### Recently Launched Satellites

**Resourcesat-2A** satellite is a follow on mission to Resourcesat-2 that provides data continuity to the user with improved frequency. The configuration is similar to Resourcesat-2 with three-tier imaging capability. The spacecraft mass is around 1,200 kg and a mission life of 5 years. The satellite was placed in polar sun synchronous orbit of 817 km altitude with an inclination of 98.69 deg.

**SCATSAT-1** is a continuity mission for Oceansat-2 Scatterometer to provide wind vector data products for weather forecasting, cyclone detection and tracking services. The satellite carries Ku-band Scatterometer similar to the one flown onboard Oceansat-2. The

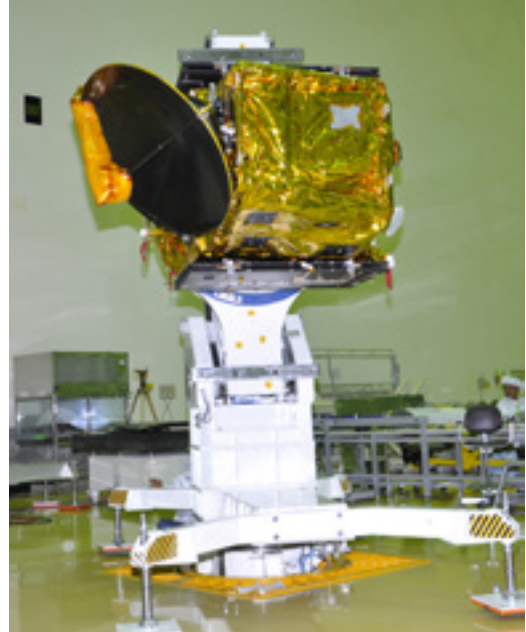


Resourcesat-2A during a pre-launch test



spacecraft is built around standard IMS-2 Bus and the mass of the spacecraft is 360 kg. The spacecraft was launched to the polar sun synchronous orbit of 720 km altitude with an inclination of 98.27 deg. The mission life of the satellite is 5 years.

**Cartosat-2** Series Satellite was launched along with other 19 co-passenger satellites. This satellite is similar to the earlier Cartosat-2 satellites. After its injection into a 505 km polar sun synchronous orbit the satellite was brought to operational configuration. The imagery of Cartosat-2 Series Satellite will be useful for cartographic applications, urban and rural applications, infrastructure planning utility management like road network monitoring, water grids, creation of land use maps, change detection and other studies.



SCATSAT-1 in clean room

### Meteorological Satellites in Service

**KALPANA-1** is an exclusive meteorological satellite launched by PSLV-C4 on September 12, 2002. It carries Very High Resolution Radiometer (VHRR) and DRT payloads to provide meteorological services. The satellite has completed nearly 13 years of life in orbit and continues to provide satisfactory imaging services.

**INSAT-3A**, which was launched on April 10, 2003, carries a Very High Resolution Radiometer and Charge Coupled Device (CCD) camera to provide meteorological services. The satellite has completed 13 and half years of life in orbit. Shortly it is planned to be decommissioned as the fuel loaded is fully consumed and satellite cannot be maintained in its allotted position.

**INSAT-3D** an advanced weather satellite, was launched on July 26, 2013 and positioned at the orbital slot of 82 deg East longitude in the geostationary orbit. It has added a new dimension to weather monitoring through its Atmospheric Sounding System, which provides vertical profiles of temperature (40 levels from surface to ~ 70 km), humidity (21 levels from surface to ~ 15 km) and integrated ozone from surface to top of the atmosphere. Payloads onboard INSAT-3D are 6 Channel Imager, 19 Channel Sounder, Data Relay Transponder (DRT) and Satellite Aided Search and Rescue (SAS&R) Transponder.

**INSAT-3DR** was launched on September 08, 2016 aboard GSLV-F05 launch vehicle and positioned at the orbital slot of 74 deg East longitude in the geostationary orbit. It is a repeat mission of INSAT-3D satellite with improved geolocation accuracy and enhanced band-to-band registration. The radiometric



measurements have been improved using Black Body calibration. It has an Atmospheric Sounding System of 19 channels (Visible-1, SWIR-6, MWIR-5, LWIR-7) capable of providing vertical profiles of temperature (40 levels from surface to ~ 70 km), humidity (21 levels from surface to ~ 15 km) and integrated ozone from surface to top of the atmosphere.

INSAT-3DR is also having an Imager capable of imaging earth and its environment in six spectral channels (Visible-1, SWIR-1, MIR-1, Water Vapour IR-1, Thermal IR 1-1, Thermal IR 2-1). It is also having a Data Relay Transponder (DRT) and a Satellite Aided Search and Rescue (SAS&R) Transponder payloads.



INSAT-3DR mounted on conical adapter

## FUTURE EARTH OBSERVATION MISSIONS

India's future Earth Observation (EO) programme envisages the continuity of the thematic series of satellites, namely, Resourcesat, Cartosat, Oceansat, RISAT, INSAT series for land, water, ocean Meteorological applications. It is also envisaged to realise a Geo Imaging Satellite (GISAT) in the geostationary orbit to enable near real time imaging. The overall aim is to maintain the continuity of services and carryout enhancements in technological capabilities with respect to sensors and payloads to meet the operational applications. In this regard, it is planned to design, develop and launch Cartosat-2 Series Satellite 3 and Cartosat-3 in the Cartosat series of satellites, Oceansat-3 and Oceansat series, and continuation of INSAT series for meteorological applications. A brief description of these future missions is given hereunder:

**Cartosat-2 Series Satellite 3** mission is a follow on mission in the Cartosat-2 Series with the primary mission objective of providing high-resolution scene specific spot imagery. This is similar configuration to earlier satellite. The satellite is planned to be launched by PSLV into a nominal altitude of 500 km. The satellite is capable of along track and across track steering, nominally up to  $\pm 26$  deg providing spot images in continuous imaging mode. Cartosat-2 Series Satellite 3 is planned to be launched by the second quarter of 2017.

**Cartosat-3:** It is an advanced, agile and new generation of satellite with panchromatic and multispectral imaging capability, with an operational life of 5 years. Many new technologies / elements are being developed like highly agile structural platform, payload platform, data handling and transmission systems, advanced onboard computer and new power electronics, dual gimbal antenna, etc. The satellite readiness is expected by first quarter of 2018.

**GISAT-1:** It is a geo imaging satellite operating from geostationary orbit to provide high temporal resolution. The GISAT-1 payload can provide a spatial resolution in the range of 50 m to 1.5 km, depending on the spectral band (VNIR, SWIR, TIR) used. The satellite platform is a modified version of I-1K bus, with a lift-off mass of 2,100 kg. The spacecraft is planned to be positioned at 93.5 deg East



longitude in the geostationary orbit of 36,000 km height to provide near real time images of the large areas of the country, under cloud free conditions, at frequent intervals. This means, selected sector-wise image every 5 minutes and entire Indian landmass image every 30 minutes at 50 m spatial resolution is possible. The potential applications include quick monitoring of disasters, natural hazards and calamities, episodic events and any short term events. These satellites will be realised for launch by 2018.

**Oceansat-3:** is a continuity mission of Oceansat-2. It has three payloads a 13-Band Ocean Color Monitor (OCM), a 2-Band Long Wave (thermal) Infrared Sea Surface Temperature Monitor (SSTM) and a Ku-Band Pencil Beam Scatterometer. Improvements planned in the Oceansat-3 are simultaneous measurement of ocean color and SST, newer applications with increased number of bands and reduced bandwidth, wind vectors at 25 km spatial resolution, improvements in signal to noise ratio, coverage from near pole to pole, etc. Oceansat-3 is planned to be launched in the year 2018.

**RISAT-1A:** is a repeat mission of RISAT-1 with C-Band Synthetic Aperture Radar (SAR) payload to facilitate cloud penetration and other earth observation applications and day / night imaging disaster management. The data from RISAT-1A will be used for applications in the areas of agriculture, forestry, soil moisture and hydrology, and ocean studies. The RISAT-1A satellite is planned to be launched in the year 2018.

## Ground Segment

The tracking support for all operational remote sensing and scientific satellites is being provided by ISRO Telemetry Tracking and Command Network (ISTRAC). ISTRAC also provides active support for Search & Rescue, Disaster Management Support and hosts space communication hub services for societal applications. ISTRAC has established a network of ground stations at Bengaluru (BL1, BL2 and BL3, BL4), Lucknow (I & II), Mauritius (I & II), Sriharikota (SHAR I & II), Port Blair, Thiruvananthapuram, Brunei, Biak-I & II (Indonesia) and the Deep Space Network Stations, namely, DSN-32 and DSN-18. The Mission Operations Complex located at Bengaluru carries out round-the-clock mission operations of all remote sensing and science satellites.

**SCATSAT-1:** SCATSAT-1 payload data is being regularly received at Shadnagar & Antarctica Ground station for Earth Observation Satellites (AGEOS) and processed routinely. First Scatterometer Payload in operational mode was supported on October 03, 2016 at AGEOS, Auxiliary Data Processing (ADP) was smooth and completed as per the turnaround time.

**Cartosat-2 Series:** The Cartosat-2 Series data ingest and level "0" initial phase operations have started since June 25, 2016 and the data reception was operationalised at Integrated Multi mission Ground segment for Earth Observation Satellites, Shadnagar.



**Resourcesat-2A:** The data chain systems and timing & data ingest systems were installed and supported the GCO data collection activities during Thermovac Tests at ISAC.

**Landsat-8 data reception:** The X-Band downlink at IMGEOs has been upgraded to receive data of Operational Land Imager (OLI) and the Thermal Infrared Sensors (TIRS) from LANDSAT-8 satellite.

**Development of S and Ka-Band Data Reception System:** In order to meet the Cartosat-3 data reception requirements, design and development of a new Ka-band data reception system has been taken up in collaboration with ECIL.

**Augmentation of 7.5 m S/X Antenna Systems at User Stations:** Existing 7.5 m S/X band Antenna Systems at all user stations have been upgraded with new digital servo and digital tracking systems. This has made data reception systems highly reliable for satellite tracking and flexibility for remotely monitoring and controlling operations. The receive chain with the present capability of 105 Mbps has been upgraded to receive signals at higher data rates. This caters for data reception from Cartosat-2 Series of Satellites and other future missions.

#### **Satellite Data Reception and Ingest Systems:**

The ground station set up at Shadnagar, Hyderabad acquires Earth Observation data from 11 Indian Remote-Sensing satellites Resourcesat-1, Resourcesat-2, Cartosat-1, Cartosat-2, Oceansat-2, RISAT- 1 SARAL, Cartosat-2A, Cartosat-2B, Cartosat-2 Series and SCATSAT-1 through 7.5 m S/X band antenna terminals with station efficiency better than 99%. Besides, data from different foreign satellites AQUA, TERRA, LANDSAT-7, LANDSAT-8, SNPP, NOAA-19 & METOP-A/B satellites are also being received, processed and archived on Shadnagar storage. Presently, the data acquired at AGEOS and SVALBARD stations is also being transferred to IMGEOs for level-0 processing, product generation, archival and dissemination. As part of the new MoU for the IGS, the IRS data acquired at these Ground stations are later sent to NRSC, Shadnagar for archival. About 12,528 satellite passes were acquired and archived during April to October 2016.

**Establishment of Doppler Weather Radars:** To improve the weather monitoring and monsoon studies, ISRO in association with IMD, has taken up establishment of five indigenous Doppler Weather Radars. The S-band DWR at Cherrapunji was established and dedicated to the Nation by Hon'ble Prime Minister in May 2016. A C-band DWR was operationalised at Thiruvananthapuram in August 2016. Third DWR at Gopalpur, Odisha that is already established is planned to be declared operational in the beginning of November 2016. Two more DWRs at Kochi and Sriharikota are under establishment, and are expected to be functional by March 2017.

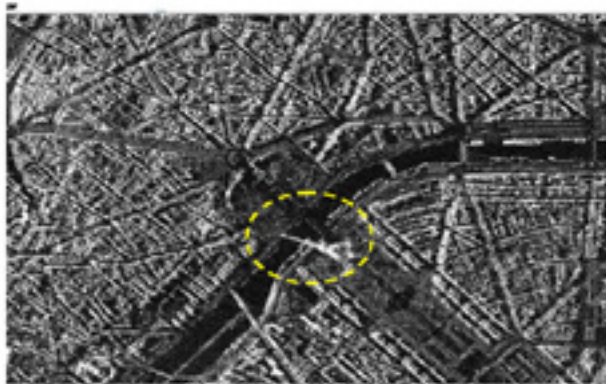




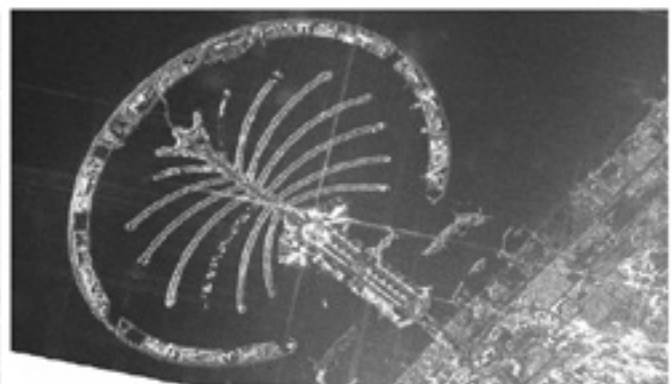
DWR at Cherrapunji

#### Data Processing, Products, Archival and Web Applications:

Emergency product generation of RISAT-1 data was supported in near real time for various disaster events - Floods (Andhra Pradesh floods, Assam floods, Telangana floods, Bihar floods, UP floods etc..) Sikkim Landslide and Charter requests. About 26,673 data products were generated. The operational software for RISAT-1 data processing was upgraded for HRS Sliding Spotlight mode. Development and Operationalisation of modules in software for improving RISAT-1 ScanSAR data products on speckle filtering scalloping, banding, etc, were completed.



Eiffel Tower, Paris

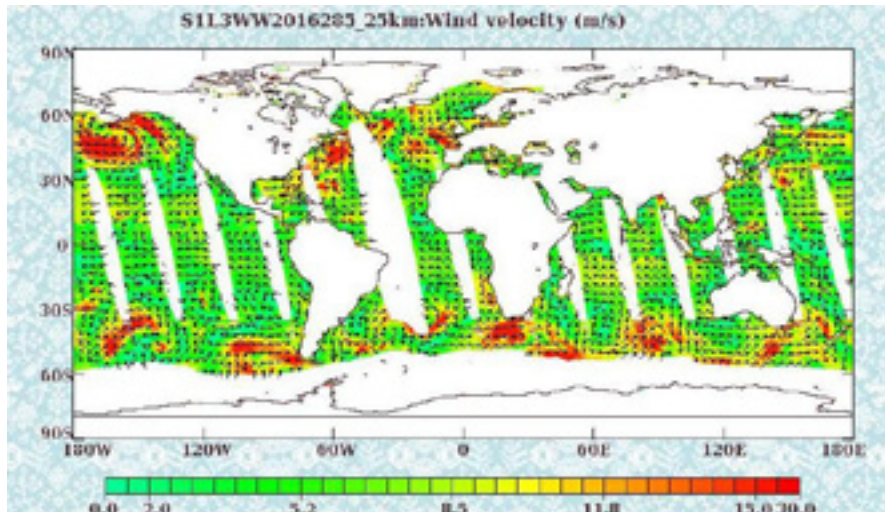


Palm Island, Dubai

Eiffel Tower, Paris (left) and Palm Island, Dubai (right) as seen by RISAT-1

Ground segment chain for SCATSAT-1 data products generation and dissemination was setup, as part of Global data processing. The OCM ROSA, NOAA-AVHRR, MODIS, METOP-A/B, and NPP data products were generated at Shadnagar including a two day time composite SCATSAT data. Landsat-8 data processing software was installed and operationalised at IMGEOs, Shadnagar. The total activities of acquisition, processing and dissemination of Landsat-7 and 8 data are being automated.

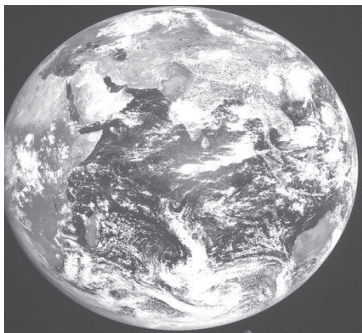




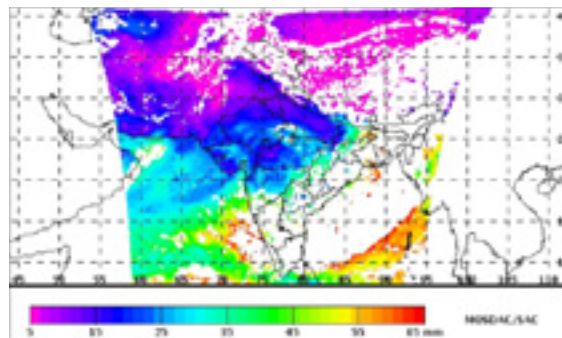
Global Wind Products from SCATSAT-1

**Data Products and special products software:** 79,561 data products were generated against various user requirements at IMGEOs Shadnagar for the period April-September, 2016. Generation of, CartoDEM was completed for Egypt (1,001,450 km<sup>2</sup>) and part of South-west Asia (5,498, 906 km<sup>2</sup>).

As part of readiness for INSAT-3DR launch DP processes for raw data extraction, radiometric correction, servo correction, navigation, fixed grid were made ready and tested on simulated data sets. The INSAT-3DR products were successfully evaluated and assured RAW data quality band to band registration, geolocation, residual attitude, etc.



First Image of Earth Disc from INSAT-3DR in the visible band (September 15, 2016, at 11:30 hrs IST)



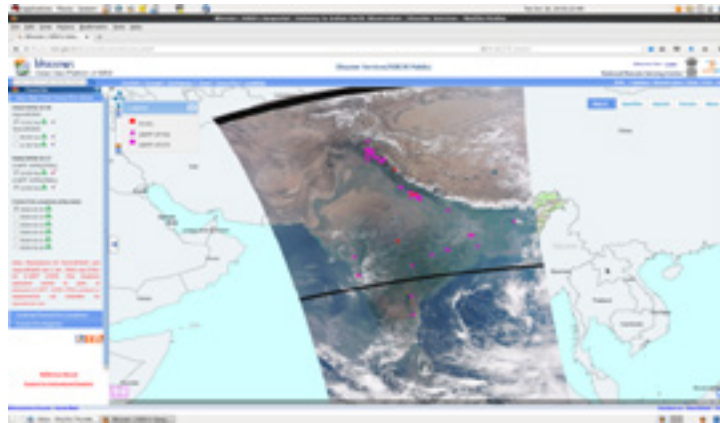
INSAT-3DR TPW 11 Oct 2016 2130 GMT

**SARAL:** Operational Geophysical Records (OGDRs) in Near Real Time in TMNRT Data Processing Facility at Shadnagar are being generated for SARAL data. About 2775 OGDRs are generated and 16737 IGDRs are retrieved from AVISO Server.

**Enhanced wind vector product:** Enhanced resolution Sigma-0 product from Ocean scatterometer (OSCAT) for land application was developed. Using the overlaps available at Orbit, footprint and slice levels an enhanced resolution sigma naught products are being developed at global scale every alternate day at 3 km and 5 km resolutions.



**Active Fire Alerts generation:** Active fire alerts were generated, disseminated and hosted at Bhuvan portal in near real time as part of forest fire monitoring and agricultural fire monitoring using Suomi-NPP VIIRS data.



Active Fire Product Generated using Suomi-NPP VIIRS

**Snow melt study products:** Snow binary map, Land Surface Temperature (LST), and Pseudo albedo products are being generated regularly using S-NPP VIIRS data.

**Geophysical and Special products:** Special emphasis was given to generate satellite products such as NDVI, Vegetation Fraction products from OCM2, Filtered NDVI, Oceansat-2 Land surface albedo (broad band and visible), surface water body, snow albedo, temperature profiles and surface reflectance for atmospheric correction.

**CAL-VAL Activities:** Optical, Microwave SAR CAL-VAL Facility at IMGEOs, Shadnagar for Space borne, Airborne Optical and SAR Sensors was established to national and international User Community. Corner reflectors (Trihedral and Dihedral) of various dimensions are deployed at CAL-VAL site to cater to L/C/X band frequencies and Vertical / Horizontal / Circular polarisations. CAL-VAL experiments were conducted during the favorable season of Oct-Apr for LISS-III / LISS-IV / OLI / Cartosat-1, FORE and AFT / Cartosat-2 Series to monitor the traceability and radiometric performance using CAL-VAL Targets. As a new initiative, desert sand based Calibration Site for coarse resolution sensors like AWiFS is as part being established at Jodhpur.



Optical CAL-VAL Site as viewed from Bore sight



**Data and product- quality control:** Auto Data Quality Evaluation procedures were established for SCATSAT-1 evaluation for all orbits / acquisitions for Raw / Foot Print / Orbit based strips. Cartosat-2 Series data products Geometric parameters and radiometric performance Qualification for PAN and MX sensors through continuous evaluation for various iterations and modifications were carried out in Data Processing chain for all modes, computation and assessment of Quality Parameters. About 91,057 IRS user products with 12% rejection rate are verified and certified.

**Data Dissemination:** NRSC Data Centre supports the data requirements of National and International user communities. During this year, total products disseminated were 1,26,311 which comprises of 28,165 products through sales and 98,146 free downloads through BHUVAN and Oceansat-2 portal. Foreign High Resolution data supplied is about 11,46,786 sq.km. By using ANT dump station support, IRS satellites enhanced the capacity of Global archives.

**Data dissemination through web portal:** Free satellite data download is made available through BHUVAN and Oceansat-2 Web portals. (LISS-III, AWiFS, CARTO-DEM OCM and SCATTEROMETER data is available as free download from BHUVAN and Oceansat-2 Web portals, respectively). The total number of products downloaded is about 91,156.

**Cartosat-2 series Satellite Data Processing:** NRSC has designed and developed the radiometric calibration of the Panchromatic camera data, Optical Butting Registration (OBR) estimation tool, image fusion algorithm, algorithm and software for Optical Butting noise correction for PAN and MX payload and algorithm for frame based un-even illumination correction and colour balancing of EVM-2 image frames.

## Web Services

### BHUVAN

BHUVAN [<http://bhuvan.nrsc.gov.in>] is ISRO's Geoportal providing Geospatial services and Earth observation data to users in public domain. The portal also services several users for the remote sensing application needs. The portal has witnessed about one lakh unique visitors and 800 Gb data transfer per month. The BHUVAN node implementation and configuration at Regional Centre Bengaluru, Jodhpur and Kolkata was improved and MOU for establishing Bhuvan nodes at state centres was signed by 15 state centres. About 24 servers were configured for distributing to the state centres and ministries.

During the period, 24 new application releases, 19 NICES products, four Satellite Ortho Products, six application updates and support for six application / mash-up development and 23 mobile Geo-tagging applications were carried out. Bhuvan regional nodes were established at Regional Remote Sensing Centre-Kolkata and Jodhpur; four state nodes at Andhra Pradesh, Telangana, Punjab and Madhya Pradesh and a central Ministry node at Railways. Bhuvan services cater to a variety of users, namely,

- NABARD watershed monitoring and evaluation
- Realisation of Citizen centric postal application



- Housing for All geo-tagging and monitoring
- Support to Tamil Nadu Election – 2016 as Election GIS
- Citizen Centric application for Monument Authority of India having online geo-processing
- NICES with 19 Products, SIS-DP and Disaster Services support
- Release of new version of pocket Bhuvan
- Bhuvan online mapping support for LULC, WL and LDD support and Decision support
- Telangana Water Resources Info System
- Geo-MGNREGA asset Geo-tagging support having a target of 3 Crore assets
- Holistic development of islands
- CartoDEM 30 m based elevation data with profiling as web service for IIT Bombay.

## MOSDAC

MOSDAC is the web portal for archiving, processing and disseminating the meteorological and oceanographic data of ISRO's satellite missions and ground based systems. The data products are disseminated through web based services for the needs of scientific / research community in the country. MOSDAC website is modified and a new version is released with advanced capability for visualisation and access to data. MOSDAC is a storehouse for space based weather and ocean data from missions such as INSAT-3A, KALPANA-1, INSAT-3D, Megha-Tropiques, SARAL, Oceansat-2, SCATSAT-1 and INSAT-3DR. Seasonal prediction of Indian summer monsoon rainfall and Weekly Agricultural outlook and monsoon Prediction for the year 2016 is released on MOSDAC. A unique training programme "Satellite Meteorology and Oceanography Research and Training (SMART)" has been initiated and first batch of students has already been trained with MOSDAC data. A new version of weather App for mobile is made available on MOSDAC. MOSDAC, along with SAC library, has implemented Digital Object Identifiers (DOI) based Persistent Identifiers for Data products.

## Visualisation of Earth Observation Data and Archival System (VEDAS)

VEDAS is a web based archival, dissemination and visualisation of Earth Observation derived data products for various themes with a focus on giving opportunities for academia to export Geospatial capability at SAC, Ahmedabad. It will help in the use of spatial infrastructure, information dissemination system and training on R&D platform. Content generation for VEDAS has been initiated. Solar, Wind and Wave energy and digital atlas are already available on VEDAS. Two trainings were conducted on remote sensing and CAL/VAL for 25 participants.



### **National Information system for Climate and Environment Studies (NICES)**

NICES continued to produce 43 geophysical products of which 13 are the Essential Climate Variables (ECV) pertaining to land (20), ocean (18) and atmosphere (5). These products are generated at varied temporal and spatial binning to cater to different applications using 9 Indian EO sensors and 9 international EO sensors. With the launch of SCATSAT, five geophysical parameters including ocean winds, currents, snow melt / freeze and ocean surface pressure would soon be resumed. More than 40,000 unique hits have been recorded on the NICES portal since its inception and a total 11,756 products were downloaded by users from April 01- October 27, 2016. A workshop was organised on NICES at NRSC on April 26, 2016 with the participation of delegates from Ministries, ISRO centres and other user organisations. About 75 delegates participated in the workshop.

### **Aerial Services and Digital Mapping**

The Aerial Services and Digital Mapping is a unique facility that has end-to-end capability and state-of-the-art infrastructure for Aerial Remote Sensing that comprises of data acquisition of high resolution data (up to 5 cm GSD), ground survey, photogrammetric processing, generation of high resolution digital elevation model with a vertical accuracy of 20 cm, fine contours of 0.4 m and large Scale Mapping up to 1:500 scale. Major applications are sensor validation, urban planning and data for disaster events like floods, landslides, etc. NRSC, ISRO owns and operates two Beechcraft super King Air B200 aircraft, which are being operated within the guidelines of DGCA and AAI to meet the regulatory requirements.

The aircraft utilisation during the reporting period was to the tune of 149 hours, with one of them flying for 129 hours and the other for 20 hours. Aerial surveys conducted towards some of the important tasks include: Testing and validation of systems of RCI, DRDO; Atmospheric data collection for RAWEX-2016 (Regional Aerosol Warming Experiment) under IGBP; Testing and validation of X-band MiniSAR system developed by SAC; Testing and validation of C-band DMSAR system developed by SAC. Airborne sorties are being conducted over Chitradurga (lunar terrain simulated) area for Lander sensors performance test (LPDC, LIRAP and Ka-band Altimeter) proposed in Chandrayaan-2 mission.

Under the implementing arrangement between ISRO and JPL, an airborne campaign was conducted for scientific studies using Advanced Visible and Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG) sensor and acquired data over 57 sites (total area of 22,840 sq. km). The aircraft was flown for nearly 196 hours over 84 days. The mission was executed in coordination with multiple teams from JPL, NRSC, SAC and IAF. The data was delivered to scientists of SAC, NRSC and IIRS for analysis.





Bitarkanika – Orissa



Vuyyur – Andhra Pradesh

### NNRMS - GCPL Phase-III:

It is planned to densify the Ground Control Points (GCP) for future Carto mission requirements as well as to improve current missions planimetric accuracy. It is also proposed to use airborne large format digital camera data to generate high precision ortho data for a few sites for calibrating the satellite platform. A total number of 8500 GCPs with an accuracy of better than 50 cm including 1,100 Pre-Signalised Points (PSP) are planned which involves collection of GCPs in two modes. PSPs were collected with an accuracy of better than 15 cm using Precise Point Positioning technique and GCPs were collected with an accuracy of better than 50 cm using GAGAN SBAS / Commercial DGPS services. During the current year, GCPs collection and database creation has been completed for a total of 4850 points covering North India, North Eastern region and J&K state and populated into GCPL database.

Also, during the period, airborne LFDC data at 10 cm GSD has been acquired over six sites, namely, Alwar (436 sq.km), Satara (490 sq.km) and Nizampatnam (210 sq.km) for calibration purpose. Aero triangulation and DSM generation was completed for Nizampatnam.



## Space Applications

### Satellite Communication Applications

A fleet of 13 commercial communication satellites are operating over India with communication transponders in C-band, Extended C-band, Ku-band and S-band. These transponders support the services like television, telecommunication, radio networking, strategic communication and societal applications. The prominent users of the transponders are BSNL, Doordarshan, All India Radio, strategic government users, public sector units, private VSAT operators, DTH and TV operators, banking and financial institutions, etc.

Under societal applications, ISRO / DOS has supported programmes like Tele-medicine, Tele-education and Disaster Management Support (DMS) Programmes which are solely national development oriented with an aim to address specific requirements at different strata of the society.

In order to meet additional transponder requirements from various users, about 100 transponders in C and Ku-band are leased from international satellite operators, through Antrix Corporation Limited on a back-to-back arrangement with users and satellite operators. Thus, satellite communication is playing a major role in the socio-economic development of the country.

### Television

INSAT has been a major catalyst for the expansion of Television coverage in India. DOS has made available the required transponders through INSAT / GSAT satellites and through leased capacity to cater to the needs of television service.

Doordarshan is presently operating 34 satellite channels and has a vast network of 67 Studios and 1,416 Transmitters of varying power installed throughout length and breadth of the country.

In terrestrial mode, DD1 (National) Channel coverage is estimated to be available to about 92% population of the country. Signals to these transmitters are beamed through satellites. In satellite mode, the signals are accessible to 100% population in 100% geographical area in the country.

DTH services are becoming popular with the introduction of premium services like HDTV services, on-demand movie services, etc. High power Ku-band transponders are used to support DTH television service with a smallest dish antenna all over India.

The free-to-air DTH service “DD Free Dish (Earlier DD Direct+)” of Doordarshan offers 59 TV channels. For A&N Islands, DTH service is in C-band with a bouquet of 10 channels. DD has plans to augment the capacity to carry 250 channels.



Apart from Doordharshan, the public broadcaster, 6 private DTH operators are providing service in India. It is estimated that (TRAI Report - August 2015) there are about 81.47 million registered DTH subscribers and 41.05 active DTH subscribers and about 819 TV channels are beamed in India as on in February 2016.

About 92 Ku-band transponders from both Indian and leased satellites are catering to DTH television services. Apart from DTH, about 30 C-band transponders being used for supporting Television uplink. Doordarshan alone is using a total of 19¼ Transponders (12.25 C-Band and 7 Ku-Band) of 36 MHz each on INSAT System.

### **Satellite News Gathering and Events Broadcasting**

Satellite News Gathering using INSAT system enables coverage of on-the-spot real-time news and important events at different locations for transmission to a Central Station. These live coverages are rebroadcast over respective television channels. Doordarshan alone has 16 C-band and 18 Ku-band Digital Outdoor-Broadcast Digital Satellite News Gathering terminals operating through INSAT satellites. About 5 transponders are used for DSNG services of various operators.

### **Radio Networking**

Radio Networking (RN) through INSAT provides a reliable high-fidelity programme channels for National as well as Regional Networking. Around 419 All India Radio (AIR) stations and about 600 radio transmitters have been equipped with receive terminals. AIR is utilising one C-band transponder for uplinking RN carriers across the country. 21 radio channels of AIR are broadcast through DTH platform of Doordharshan.

### **Telecommunications**

INSAT satellites have been traditionally supporting telecommunication applications for providing voice and data communications. Satellite links are the primary means of connectivity to remote and far flung regions of the country and they are the backup links for a large number of terrestrial connectivity in the mainland.

Presently, 1366 Satellite Earth Stations of different size are operating in the satellite network of BSNL, Government users, Closed user group, commercial users and broadcasters and are being utilised for telecommunications / broadcasting applications. As per provisional estimates, about 2,62,803 VSATs (excluding NICNET and VSAT micro terminals) are being used in star / mesh connectivity of various size and capabilities. Telecom services are being provided by BSNL to remote and inland through satellite media in C-band and Ku-band from the main earth stations as backhaul point to point connections. BSNL is also providing GSM connectivity, ATM / Banking connectivity through more than 20,000 IPSTAR VSATs as well as one by two voice channel connectivity to remote areas through 5,824 DSPTs (Digital Satellite Phone Terminal).



Captive satellite based networks for NTPC, BISAG, ONGC, ERNET, IOCL, ICAR, POLNET, Karnataka Power Transmission Corporation Ltd., Indian Railway Project Management Unit and private enterprises are operational. A number of other captive government networks like Indian Coast Guard, Ministry of Defence, Cabinet Secretariat, DRDO, etc., are also working with INSAT / GSAT satellites.

## Telemedicine

The Telemedicine programme connects remote / rural / medical college hospitals and Mobile Units through the Indian satellites to major specialty hospitals in cities and towns. The telemedicine technology utilises Information & Communication Technology (ICT) based system consisting of customised medical software integrated with computer hardware along with medical diagnostic instruments connected to VSATs. Presently, around 120 Telemedicine nodes are operational across the country.

During the year an MoU was entered into with Ministry of Health & Family Welfare for operations of the established Telemedicine nodes and establishment of about 14 new telemedicine nodes. An MoU was also entered into with Ministry of Social Justice & Empowerment (MoSJ&E) for the establishment of 4 Telemedicine Centres. The mobile van of SGPGI, Lucknow, was augmented with deployable VSAT to provide TM facilities at Kumbh Mela, Ujjain (MP). More than 1,000 pilgrims were benefited.

Continuing Medical Education (CME) programmes are conducted on monthly basis from DECU studio. Medical experts / doctors share their knowledge and experiences and interact with the connected remote hospitals. By November 2016, seven CMEs were conducted and four more are planned during the financial year. A social research report is also drafted for each CME.

## Tele-education

Under Tele-education programme, the teaching sessions conducted from customised studio are telecast through satellite(s) for connect to schools and colleges spread across. It has manifold objectives to supplement the curriculum-based teaching, imparting effective teacher training and providing access to experienced resource persons, thus, resulting in effective delivery of quality education to the nook and corners. EDUSAT provided connectivity to schools, colleges and higher levels of education and also supported non-formal education including development communication.

Tele-education Programme started in 2004 was implemented in three phases: pilot, semi-operational and operational phases. In association with State / Central user agencies, 83 networks were implemented connecting around 5000 Interactive (SITs) and 55,000 Receive Only Terminals (ROTs), covering 26 States & 03 Union Territories. At present, around 47 networks are operational in Haryana, Punjab, Chhattisgarh, Andhra Pradesh, Telangana, Kerala, Karnataka, Gujarat, Tamilnadu, Maharashtra and Rajasthan.



During the year, an MoU is entered into with Ministry of Skill Development & Entrepreneurship (MSDE) to set up a Space-based Distance Learning Programme (SDLP). Re-energising the TE networks of North-East states is taken up.

### **Mobile Satellite Services (MSS)**

The MSS Service provides the communication to the portable and moving devices. There are two classes of services namely Type-C and Type-D. Type-C is a low bit rate one-way reporting service using shared channels with portable and hand-held terminals. Type-D is a two-way voice communication service with small portable satellite terminal.

### **Satellite Aided Search and Rescue (SAS&R)**

India is a member of the international COSPAS-SARSAT programme for providing distress alert and position location service through Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) Search And Rescue (SAR) satellite system. Under this programme, India has established two Local User Terminals (LUTs) at Lucknow and Bengaluru. The Indian Mission Control Centre (INMCC) is located at ISTRAC, Bengaluru. The system is operational from the past 25 years.

INSAT-3D located at 82 deg East and INSAT-3DR located 74 deg East, are equipped with a 406 MHz Search and Rescue (SAR) payload. These payloads pick up and relay alert signals originating from the distress beacons of maritime, aviation and land users. Indian LUTs provide coverage to a large part of the Indian Ocean region rendering distress alert services to Bangladesh, Bhutan, Maldives, Nepal, Seychelles, Sri Lanka and Tanzania.

The distress alert messages concerning the Indian service area, detected at INMCC, are passed on to Maritime Rescue Coordination Centres (MRCCs) of Indian Coast Guard (Mumbai, Chennai, Port Blair), and Rescue Coordination Centres (RCCs) of AAI (Mumbai, Kolkata, Delhi, Chennai). The search and rescue activities are carried out by Coast Guard, Navy and Air Force. INMCC is linked to the RCCs, MRCCs, SPOCs (Search and Rescue Points of Contact) and other International MCCs (Mission Control Centres) through Aeronautical Fixed Telecommunication Network (AFTN) and through FTP (File Transfer Protocol) links. The Indian LUTs and MCC provide round the clock service and maintain the database of all 406 MHz registered beacons carried onboard Indian ships and aircraft.

During 2016, INMCC provided search and rescue support to six distress incidents in Indian service area through Indian system and contributed to saving of 34 human lives. About 815 new radio beacons were added in Indian database (most of them for Aviation applications). The INMCC has the facility to register and maintain the user and beacon details. There are about 841 registered user agencies (Maritime and Aviation) in India with an Indian beacon population of more than 15,111 in the database. The next generation system MEOSAR is under implementation phase and is expected to operate under Early Operations Capability (EOC) by the middle of 2018.



## Standard Time and Frequency Signal Dissemination Services

A Standard Time and Frequency Signal (STFS) Dissemination Service using INSAT system is provided by the National Physical Laboratory. This service is available round-the-clock in a broadcast mode and is receivable on a set up consisting of a receive antenna, a front-end converter, an FM demodulator and a microprocessor controlled signal decoder. The service consists of a train of 5 KHz bursts signal, which is frequency modulated on the carrier. The timing service has a precision of better than one microsecond and accuracy of better than 20 microseconds.

## Navigation – NavIC and GAGAN- Applications

NavIC reference receivers have been distributed among Academic Institutes, ISRO centres, Govt. R&D organisations, etc for field trial data collection as well as for the development of applications. NavIC receivers are deployed in 15 ships sailing in and around India for study purpose and the data from these ships are being collected. Meetings are being held with MHA and Ministry of Shipping for use of NavIC in fishing vessel tracking.

Towards utilising NavIC for the maritime services, a proposal was submitted to International Maritime Organisation (IMO) for recognising NavIC as part of World Wide Radio Navigation System. The Maritime Safety Committee (MSC) of IMO has considered the proposal for further deliberations in its technical body NCSR.

An MOU is signed between ISRO and Ministry of Railways for implementing various projects like unmanned level crossings systems, train tracking and passenger information system using GAGAN / NavIC systems.

An Inter-Ministerial Group (IMG), Chaired by Secretary, MoCA has been constituted by AAI to explore and promote the usage of GAGAN for non-aviation usage. Geo-tagging the resources and infrastructure, alignments of roads / tracks, survey maps, etc. using GAGAN / NavIC is completed for Departments of Posts, Telecommunication, Tourism, etc.

IRNSS and GAGAN Utilisation Program (UP) to spread the awareness about India's satellite navigation programmes among academic institutes have been initiated by Space Application Centre. Accordingly, an Announcement of Opportunity (AO) was released on SAC website in May 2016 to invite the proposals from various academic and private institutes in India. 36 proposals on topics like ionosphere, differential NavIC, navigation and scientific application and navigation algorithms were received and 33 proposals were found suitable.

## Satellite Meteorology

With the launch of INSAT-3DR and SCATSAT-1, there is an increased availability of meteorological data for applications like numerical weather prediction, rainfall estimation, cyclone detection and tracking,



etc. Rainfall retrieval algorithm using satellite microwave brightness temperatures and its validation using ground based rain gauge data was carried out. Fusion of INSAT-3D (which gives temperature profile over cloud free regions) and COSMIC Temperature (which is based on radio occultation technique which gives measurements over cloudy areas as well) data was used to improve spatio-temporal coverage of this parameter. Weather forecasts are being disseminated on daily basis by utilising satellite and ground observations and are being extensively validated with high density rain gauge network over regions like Karnataka. These forecasts are of value, especially during times of heavy rainfall, cyclone, heat wave, fog, etc. Heat wave forecasts were also carried out with the model forecasts which had assimilated INSAT-3D temperatures. Improved assimilation schemes to utilise products like land surface temperature was carried out.

The meteorological data from Kalpana-1, INSAT-3D and INSAT-3DR satellites is processed and disseminated by INSAT Meteorological Data Processing System (IMDPS) of India Meteorological Department (IMD). The performance of the system during the current year has been maintained to the level of 98% operation efficiency (24x365 basis). Satellite images are used in monitoring Cyclones. Intensity and position of cyclones is given to forecasters in real time using Dvorak technique. Satellite data and images are also used in monitoring various other significant weather phenomena such as fog and thunderstorms.

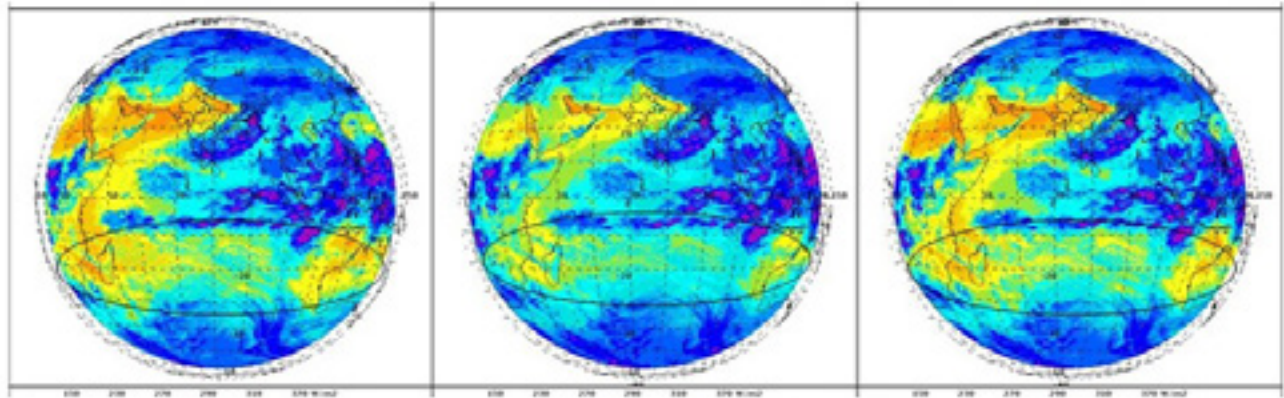
A methodology to derive tropical deep convective cloud core with cloud top altitudes from MT-SAPHIR data has been developed. INSAT-3D and INSAT-3A derived atmospheric motion vectors continue to be important source of wind measurements over the region. INSAT-3D derived parameters like stability indices, fog, etc., are being utilised for short range forecasting or nowcasting. Estimation of Cloud fraction was retrieved using radiance and reflectance measurements from Thermal Infrared and visible (VIS) channels respectively along with Water Vapour (WV) channel from INSAT-3D, which acquires data round the clock at half-hourly intervals. Forty-eight products, on a daily basis, at half-hourly interval each have been generated starting from October 2016.

A joint Calibration / Validation (Cal/Val) campaign (April 19, 2016 to April 23, 2016) was carried out successfully at Rann of Kutch, Gujarat by IMD and SAC (ISRO). A joint report of Cal/Val campaign results has been prepared and site has been accepted for conducting regular Cal/Val campaign for INSAT-3D/3DR Cal/Val.

IMD has installed 682 Automatic Weather Stations (AWS) and other agencies have installed about 1200 AWS all over the country. IMD has also installed 1350 Automatic Rain Gauge (ARG) Stations. AWS and ARG services are operational by using the Data Relay Transponders (DRT) of INSAT-3A and INSAT-3D for the relay of Meteorological, Hydrological, Agro-Meteorological and Oceanographic data from unattended stations.

IMD is in the process of upgrading the network of Cyclone Warning Dissemination System (CWDS) by the ISRO developed DTH based Disaster Warning Dissemination Systems (DWDS). About 300 systems have been successfully installed.



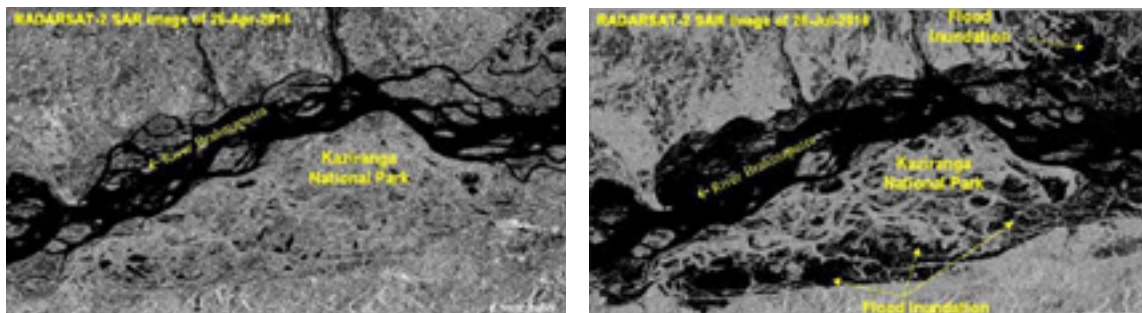


Outgoing Longwave Radiation (INSAT-3D and INSAT-3DR)

### Disaster Management Support (DMS) Programme

The Disaster Management Support (DMS) Programme of ISRO provides space based data and information as well as communication means for efficient management of disasters. The Decision Support Centre (DMS-DSC) established at NRSC is actively engaged in monitoring natural disasters such as flood, cyclone, landslides, earthquakes and forest fires. The major calamities faced by the country during the reporting period were wide spread floods in 11 states and a major forest fire in Uttarakhand State.

**Floods:** During 2016, near real-time monitoring was done for major floods in Assam, Bihar, Uttar Pradesh, Madhya Pradesh, West Bengal, Odisha, Andhra Pradesh, Rajasthan, Arunachal Pradesh, Maharashtra and Manipur. Using predominantly microwave data from RISAT-1 and Radarsat-2 satellites, more than 110 flood inundation maps were disseminated to the concerned Relief Commissioners, Ministry of Home Affairs, National Disaster Management Authority, National Disaster Response Force, Central Water Commission, India Meteorological Department and the State Government departments.



Flooding in Kaziranga National Park, Assam during July 2016  
(Channels of River Brahmaputra is given for comparison)

Based on the request from Assam state, the Flood Hazard Zonation Atlas of Assam which was published in 2011 was revised, incorporating the information for 18 years from 1998 to 2015. The atlas was released by Government of Assam in September 2016.



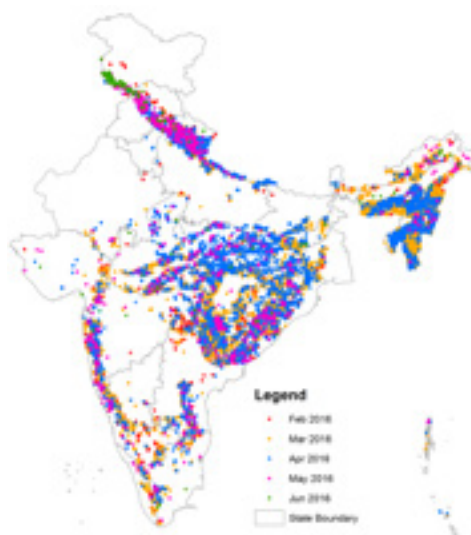
**Landslides-induced damming across Kanaka river in Sikkim:** A landslide that occurred in the Kanaka River valley near Mantam in Sikkim in the month of August, 2016, caused blocking of the river flow and a temporary lake formation. Using very high resolution Cartosat-2B data, the spread and volume of the impoundment were estimated and the information was sent to MHA, NDMA, CWC, GSI and Sikkim State Government. The input was used by these agencies to assess the ground situation and for taking suitable management measures.

**Cyclones:** The depressions formed in the Bay of Bengal were monitored including the cyclone track and intensity were predicted. All the information was regularly updated on the MOSDAC website (<http://www.mosdac.gov.in>) as part of information dissemination. The Tropical Cyclone Vardah that made landfall near Chennai city, Tamilnadu on December 12, 2016, with peak intensity of 130 km/h, caused wide spread damages due to heavy wind low-lying areas in three districts – Chennai, Thiruvallur and Kanchipuram- and maps showing vulnerable areas with respect to nearby streams were derived from satellite data and provided to Govt. of Tamilnadu in advance for preparatory activities. Periodic status of flood inundated areas after the cyclone also were provided.

**Forest Fire:** In the 2016 fire season, many fire detections were done using satellite data. Value added active fire locations are being disseminated through Bhuvan.

Near real time observations were provided to the Ministry of Home Affairs and the Uttarakhand State Government for addressing the forest fire that occurred in Uttarakhand in March 2016. During April-24 to May- 04, 2016, nearly 1600 active forest fire detections were done in the Uttarakhand Forests. These large scale forest fire incidents were studied in detail using Earth Observation inputs. Wind and other meteorological parameters at 10-km spatial resolution, simulated using WRF model, were used for quantifying and tracking the dispersion of pollutants during the forest fire incidents.

Near real time observations on agricultural residue burning in four states (Rajasthan, Punjab, Haryana and Uttar Pradesh) were also provided to the Ministry of Environment, Forests and Climate Change.



Forest Fire Locations during February-June 2016



## Development of Early Warning Systems

**Flood:** A Web-enabled real-time spatial flood forecast system is developed for the Godavari and Mahanadi Basins. Flood forecast in the Godavari basin is being issued with a lead time of 2 days and flood discharge computation accuracy of more than 87%. The model was successfully implemented during the monsoon period of 2016, in collaboration with CWC and IMD. Web-enabled flood forecast system for the Mahanadi basin was also implemented in 2016 monsoon period.

Spatial runoff in the Godavari and Mahanadi basins are being computed using the high density rainfall point data. One-day forecast runoff in both the basins are computed using IMD WRF data and the runoff products are being disseminated through the Bhuvan web-portal.

The Flood Early Warning System (FLEWS) is implemented for all flood prone districts of Assam. The percentage of success of the early warnings was about 87% in 2016.

**Landslide:** An Early warning system for rainfall triggered landslides along the pilgrimage and tourists route corridors in Uttarakhand and Himachal Pradesh was operational during the Monsoon season in 2016. Thunder storm predictions for Uttarakhand and Himachal Pradesh were provided and country-wide heatwave forecasts were also carried out during the year. These forecasts were disseminated through Bhuvan and MOSDAC portals.

**National Database for Emergency Management (NDEM):** NDEM products and services are being disseminated to all 36 States / UTs. An exclusive online module on 'Daily Rainfall Statistics Updation' is operational on NDEM platform for the States / UTs to feed data on rainfall and damage statistics for Ministry of Home Affairs. The Geo portal is enriched with more than 3 Million Point of Interests as procured service, which are updated half yearly.

NDEM services are provided to National Disaster Response Force (NDRF) for supporting relief management activities. A customised web portal and Mobile App for Relief Management, Attribute Collection and Geo-tagging of emergency facilities are operational for NDRF. Exclusive training programmes were also conducted for NDRF officials on 'NDEM – NDRF customised portal'.

**High Resolution DEM Generation:** An ALTM Digital Elevation Model (DEM) at 0.25 m height accuracy in MSL datum, contours at 0.5 m interval, orthophotos and Geo database layers compatible to 1:5000 scale were created for 15,518 sq km in Brahmaputra Basin.

**International cooperation in DMS:** ISRO is a signatory of the International Charter 'Space and Major Disasters', which aims at providing a unified system of space data acquisition and delivery to users affected by disasters. In 2016, ISRO supported 23 disaster events in 10 countries by providing 42 data sets from IRS satellites.

## Remote Sensing Applications

Remote sensing application projects are being carried out through a well-established multi-pronged implementation architecture consisting of various centres of ISRO, central and state departments,



academia and others. National Remote Sensing Centre (NRSC), Hyderabad along with its Regional Remote Sensing Centres (RRSCs), Space Application Centre (SAC), Ahmedabad, North-Eastern Space Application Centre (NE-SAC), Shillong and the State Remote Sensing Application Centres play a key role for effective utilisation of space technology in the country.

User Ministries of State and Central Government departments and other institutions utilise remote sensing technology. Some of these ministries have institutionalised or internalised the remote sensing applications in their ministries or departments. In addition, private sector, Non-Governmental Organisations and academia also utilise this technology in different developmental sectors. Some of the major application projects carried out during the year 2016-17 are highlighted in the following sections:

### **Crop Production Forecast**

Under the FASAL project, ISRO has developed the methodology for in-season crop production forecast of 8 major crops in the country and it is being operationally executed by Mahalanobis National Crop Forecasting Centre (MNCFC), Ministry of Agriculture and Farmers Welfare. MNCFC provides Rabi Pulse crops area estimates for major pulse growing states of India. There is about 15% reduction in rabi pulses area in 2015-16 compared to 2014-15. Pre-harvest yield for mustard is predicted using GEO-LEO satellite data at 1 km grid resolution for five states where the variability of spatial yield is found to be 0.8 to 3.5 tons per hectare.

**Crop Insurance and Damage Assessment:** In order to assess the feasibility of using satellite data for crop condition assessment towards Crop Insurance scheme, a new initiative is undertaken, with multi-institutional participation (including NRSC). Currently, the kharif and rabi crops at district level are covered under this. Efforts on improving the area-yield model as input for crop insurance mechanism are ongoing, in collaboration with Agricultural Insurance Company of India Ltd (AICIL), New Delhi.

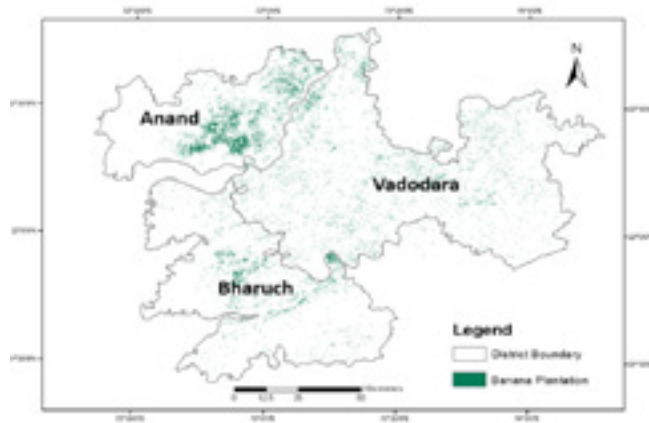
A Methodology is developed for assessing the crop damage due to extreme weather events, by integrating satellite data derived inputs such as Land Surface Water Index (LSWI), Normalised Vegetation Index (NDVI) and ancillary data on rainfall, temperature and wind speed. This methodology was applied in different districts and crop zones to evolve geospatial decision support system to monitor the effect of extreme weather events on crops.

### **CHAMAN**

Ministry of Agriculture & Farmers Welfare launched a programme, called CHAMAN (Coordinated Horticulture Assessment & Management using geoinformatics) during September, 2014, to use space technology for better horticultural inventory and development. It is being jointly executed by ISRO and MNCFC. The main objectives are area assessment and production forecasting of 7 major horticultural crops in about 180 districts, geospatial applications for Horticultural Development & Management Planning and scientific studies for crop identification, yield modelling & disease assessment. Under this project, inventory of Orchard for Mango, Citrus and Banana are generated for 25 districts and is in



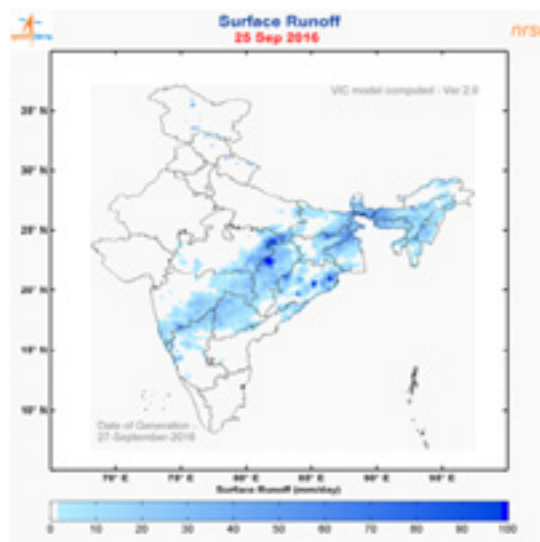
progress in other districts. Production estimations for Potato, Tomato, Chilli and Onion (in late Kharif and Rabi) are operational in 5 States. Using long-term satellite data, 952 Hectare (Ha) of mango orchards and 12,733 Ha of apple orchards are identified for rejuvenation.



Classified Banana Orchards for Districts of Gujarat

### Estimation of Grid-wise Periodic Water Balance Components at National Level

A national level hydrological modelling framework was developed for estimating in-season hydrological fluxes and deriving grid-wise geospatial products of the fluxes, viz., surface run-off, soil moisture and evapotranspiration. The input for the model are meteorological parameters, soil parameter, vegetation and terrain parameters. The products are valuable inputs for quantifying spatial and temporal variations in water resources, water budgeting and water resources management. The near real time execution of the established hydrological model frame work (at both 9 min & 3 min grid level) is operationalised with near real time meteorological data to derive water balance components on a daily basis. The model generated products, i.e., surface run-off, soil moisture and evapotranspiration are published daily in Bhuvan web portal.



Surface run-off as on October 11, 2016, at 3 min grid resolution

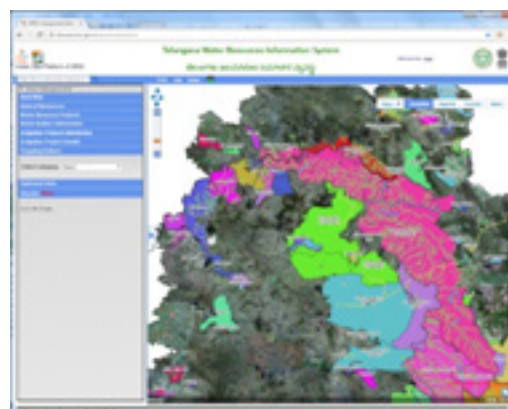


## Water Body Information System

The status of all the water bodies (> 2 ha area) in the country is being monitored using satellite images and water spread area information is provided on a fortnightly basis. Data from Indian remote sensing satellites - Resourcesat-2 and RISAT-1 - are regularly processed to generate water spread area information and is made available through Bhuvan. The waterbody information system provides an integrated view of water- spread dynamics and its statistics for about 12,500 water bodies (with area > 50ha) in the country. The information and visualisation include fortnightly water spread area, graphical representation of multi-temporal water spread and monthly scenarios for each water body. It also provides regional water spread scenarios at river basin, sub-basin, district, and state level.

## Telangana Water Resources Information System

A Memorandum of Understanding was signed between the Irrigation and CAD (I&CAD) Department, Government of Telangana, Hyderabad and NRSC, ISRO on August 06, 2016 to use geospatial technologies for effective management of Water Resources in the State. An exclusive geoportal called "Telangana Water Resources Information System (TWRIS)" is developed on Bhuvan geospatial platform, with mechanism for online field data updation and simplified monitoring tools for effective management of water resources. It comprises of Decision Support System on water resources, provisions for online monitoring of Minor; Medium and Major irrigation infrastructure and projects, and dynamic management options of important parameters by decision makers. The geoportal contains datasets on Natural Resources, Water Resource Projects, Surface Waterbodies, Irrigation Projects, Cropping Pattern and Groundwater level data. Daily updates from Automatic Weather Stations (AWS), Reservoir water level and fortnightly water spread information are published on the Geoportal.



Telangana Water Resources Information System-MoU Signing Ceremony

## Indian Scientific Expedition to Antarctica

A team of two scientists from NRSC participated in 35th Indian Scientific Expedition to Antarctica (ISEA) during austral summer of 2015-16. To understand melt/freeze dynamics and its response to microwave remote sensing data, snow properties were observed using GPR (500 MHz in-house developed and 1GHz & 200MHz commercial) and snow fork (density & wetness) near Bharati and Maitri Indian stations. GPR Profiles were collected on sea ice and on ice sheet to measure the thickness.





Maitri Earth Station, Antarctica

### **AMRUT - GIS Based Master Plan Formulation**

AMRUT programme is being implemented for 500 cities with the aim of developing detailed infrastructural planning. NRSC and Ministry of Urban Development signed an MoU on August 17, 2016 for the creation of a 1:4,000 Scale Urban geospatial database for GIS based Master Plan Formulation. Very High Resolution Satellite data (better than 1m spatial resolution) is being used for 1:4,000 scale GIS data creation. AMRUT National meet was conducted with all State-level Mission directors at NRSC on October 20, 2016 to finalise the modalities of State Action Plan (SAP). 113 cities have initiated action for geospatial data creation under the State Action Plan.

### **GAIL Pipeline Monitoring using Very High Resolution Satellite Data**

The Geospatial technology for GAIL pipeline monitoring and surveillance application was developed as an alternative to the current monthly helicopter survey. The application has been evaluated over DVPL (Dahej-Vemar-Vijaipur) pipeline segment (610-line km) for technology feasibility using monthly VHRS data during January 2015 to June 2015 and operational feasibility during January 2016 to June 2016. The Bhuvan-GAIL geospatial portal was launched for online monitoring of the right of usage along the gas pipeline. GAIL is planning to implement a similar study along its entire pipeline network in a phased manner.

### **National Land Use / Land Cover mapping on 1:250,000 scale using temporal AWiFS data: Thirteenth Cycle**

Under NR-CENSUS programme, the 13<sup>th</sup> cycle of mapping of Land Use Land Cover (LULC) at 55m resolution, using multi-temporal satellite data, is in progress. Under this programme, automated land cover mapping is adopted in computing seasonal sown areas with about 90% accuracy. Forest cover and shifting cultivation mapping are also being automated. 10 cycles of LULC database on 250,000 scale, was converted to fractional areas (5 km grid) of kharif crop, rabi crop, net sown and fallow lands.



### **National Land Use / Land Cover mapping on 1:50,000 scale using temporal LISS III Data: Third Cycle**

Under NR-CENSUS program, the third cycle of mapping of Land Use Land Cover at 23m resolution, using multi-temporal LISSIII satellite data, is in progress. Out of 706 grids of 100km X 100km dimension at the national level, mapping is progressing in 80 grids.

### **Monitoring Land Use / Land Cover Change Trajectories in Selected Hot Spots of India**

Spatial database on land use / land cover generated for the country using LISS-III data acquired during 2005-06 and 2011-12 facilitated mapping of land transformations at national level. Many areas are experiencing land transformations in the country because of various developmental processes and also due to varying type of degradation. In the light of this background, land transformations in terms of positive or negative, reversible or irreversible and transformation due to natural, cyclical or anthropogenic causes were undertaken for selected sites in the country on 1: 10,000 scale for further investigation and analysis.

### **Natural Resource Census (NRC) - Land Degradation Mapping: Second Cycle**

The land degradation status on 1:50,000 scale for the whole country has been initiated with the objectives to prepare land degradation map for the year 2015-16 using three seasons (kharif, rabi, zaid) Resourcesat-2 LISS-III data as well as to prepare land degradation change map between the base year 2005-06 and 2015-16. The project is being executed through online mapping using Bhuvan web services. The classification scheme adopted include eight Land Degradation processes (water erosion, wind erosion, water logging, salinisation / alkalinisation, acidification, Glacial, Anthropogenic and others) and 37 land degradation classes. Mapping is in progress for 133 grids of 100km X 100km dimension, out of total 706 grids, at national level.

### **Desertification and Land Degradation**

Desertification and land degradation status maps on 1:50,000 scale for the time frame 2011-13 and 2003-04 were prepared using IRS LISS-III data for Bokaro (Jharkhand) and Kanpur Dehat (UP) districts. State-wise Desertification and Land Degradation maps on 1:500,000 scale, prepared using AWiFS data of 2011-13 and 2003-05 and the corresponding area statistics were compiled as "Desertification and Land Degradation Atlas of India". The atlas was released jointly with MoEF & CC and uploaded on web portals of MoEF & CC and VEDAS.

### **Monitoring of Integrated Watershed Management Programme (IWMP) Watersheds using Geospatial Technologies**

Integrated Watershed Management Programme is a flagship programme of Department of Land Resources (DoLR), Ministry of Rural Development, Government of India. Watershed Management is one



of the key interventions for improving water resources and conserving soil in the rain-fed areas of the country. Further, such data will be of immense help in tracking the implementation, applying midcourse corrections and for assessing long-term effectiveness of the programme. The Monitoring & Evaluation (M&E) of the IWMP projects is extended to the whole country, for about 86,000 watersheds.

Watershed information is served using a Web-GIS interface on Bhuvan Geo-portal (SRISHTI) and is supported by a smart phone application (DRISHTI) to report field accomplishments as geotags. Drishti enables hierarchical visualisation of watershed by administrative units, overlaid with natural resources' database, as well as cadastral boundaries, wherever available. Geospatial tools for spatial database creation, planning watershed development activities and its verification by appropriate authorities. Currently, data of ~ 58,000 micro-watersheds comprising of 5962 projects is uploaded onto Bhuvan. Nearly 4.84 Lakh geo tagged field photographs are placed on Srishti from all state nodal agency teams, facilitating transparent and precise reporting.

### **Geospatial Initiatives under Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA)**

MNREGA was initiated with the objective of rural employment generation, which include the creation of durable assets such as roads, canals, ponds and wells. Geospatial technology is used to track assets' creation under MNREGA. This will enhance the evaluation and monitoring of the project by giving timely and accurate information. The assets' data are captured through mobile app and till now about 25 lakhs assets have been uploaded to the web portal. Training was provided to 220 personnel from the Ministry in utilising the technology.

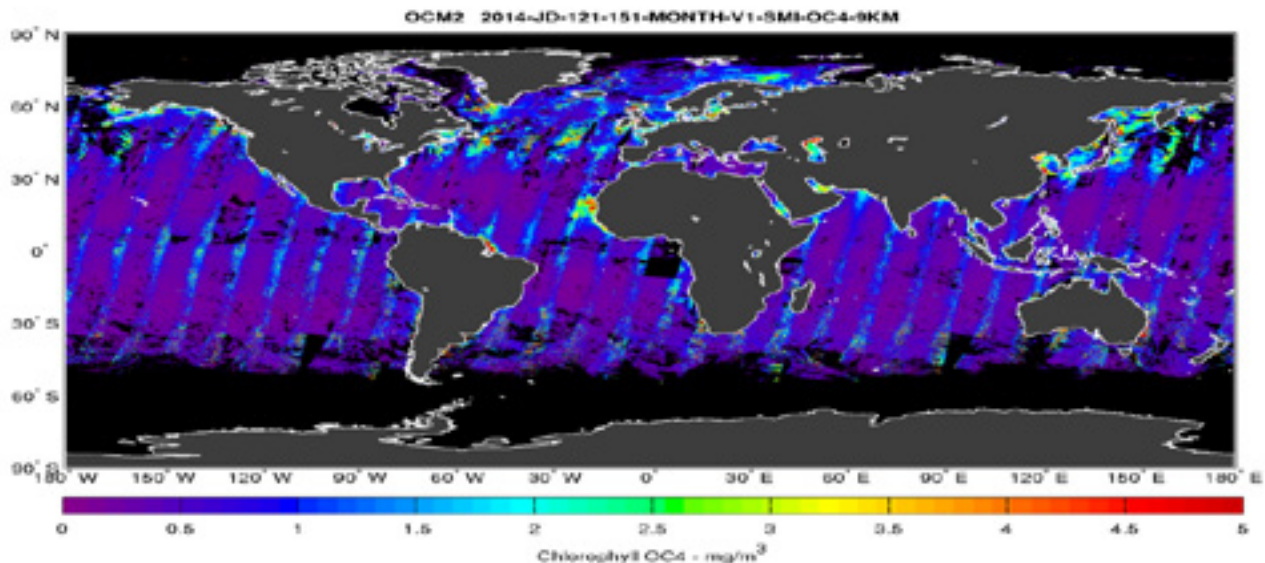
### **Automated Annual Forest Cover Loss identification using IRS AWiFS**

An Algorithm was developed for the automated identification of annual forest cover loss using IRS AWiFS data. Locations where changes were noticed have been subjected to visual quality check to ensure no errors of commission. Field verification and corroboration with high resolution satellite data have also been carried out to ensure accuracy. Identified alert locations are published on Bhuvan. An Android mobile application has been developed for collection of field attributes.

### **Ocean Applications: Global and Regional Monthly Binned Chlorophyll-a Products**

Chlorophyll-a concentration is one of the important Essential Climate Variables (ECVs) and is derived from ocean colour remote sensing. Weekly and Monthly Chlorophyll products over the North Indian Ocean (NIO) region and at Global level are generated using OCM-2 data through an automated data processing chain. The derived chlorophyll concentration is useful for resolving inter-annual to decadal changes in oceanic phytoplankton biomass in response to global environmental changes.





### Water Level Retrieval using AltiKa waveform data

Water level were retrieved for inland water bodies (10 reservoirs and 10 rivers) using SARAL-AltiKa waveform datasets. This information, along with data on AltiKa tracks, retrieved locations, etc., are published on VEDAS.

**Empowering Panchayati Raj Institutions Spatially (EPRIS):** It is a comprehensive outreach programme initiated by ISRO, DOS to build the capacity for grass root-level planners towards spatial resource-based integrated developmental planning in rural areas. The goal is to empower Panchayati Raj Institutions for resource-based and integrated spatial developmental planning in a user-friendly enabling environment towards e-governance. Activities carried out under this project include (a) Organisation of several capacity building programmes for PRIs, line departments, academia and NGOs, (b) Asset mapping using Bhuvan Panchayat mobile application and (c) Activity planning at three tiers of Panchayati Raj along with its implementation and monitoring.

Under EPRIS, 7,37,113 assets have so far been mapped. MoUs were signed with 33 partner institutions for covering 22,506 Gram Panchayats. Additionally, 28 academic institutions have come forward to cover 4,919 Gram Panchayats. 4,450 people are trained so far on the utilisation of the Geospatial tools.

**Bhuvan Gurukul:** Bhuvan Gurukul is a browser based, multi-user, multi-room video conference system for collaborative learning and discussions related to Bhuvan. Using this application, upto 30 participants can have simultaneous interaction in a single room and multiple such rooms can function simultaneously. About 2000 participants were trained since April 2016.

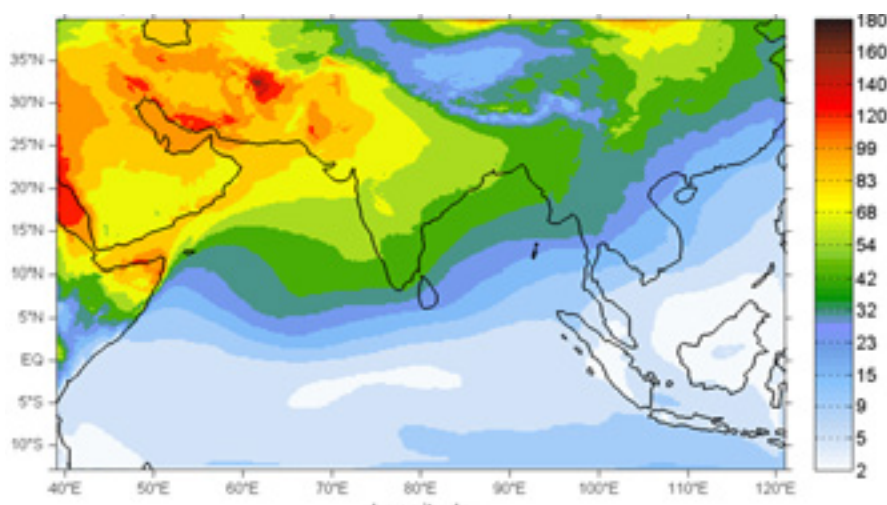


## R & D Studies

### Locating fresh water in thin and shallow coastal aquifers

Shallow fresh water coastal aquifers are thin and generally buried under recent deposits compared to deep aquifers, which are saline in coastal areas. Sea water intrusion pollutes the limited fresh water resources easily through tidal activity. Detecting these aquifers is a major challenge for the sustainability of drinking water sources in these perennially fresh water deficient regions. The study was taken up in a beach ridge and swale complex area covering 20 habitations in Andhra Pradesh coast, India. Ground Penetrating Radar data showed that the water table of the study area varies between 1.4–3 m below the ground and the depth of the fresh water aquifers varies between 3-6 m.

Air quality simulations have been carried out for the month of May and June 2016 over South Asia at 27 km horizontal resolution with 30 vertical levels up to 10 hecta pascal (hpa) to evaluate the performance of the WRF-Chem modelling system. Meteorological Initial Conditions (ICs) and lateral Boundary Conditions (BCs) are derived from the National Centre for Environmental Prediction (NCEP) Global Forecasting System (GFS) data for  $N_2O$ ,  $CO_2$ ,  $CO$ ,  $CH_4$ ,  $SO_2$ ,  $SF_6$ ,  $NO_x$  and NMVOC with a 0.1 x 0.1 spatial resolution. The gas-phase chemistry is based on the Carbon-Bond Mechanism Version Z (CBM-Z). The simulated mean surface concentration of Particulate Matter (PM) 2.5 for May and June 2016 is shown in the figure. The model simulates higher CO and  $NO_x$  concentrations over the Indo-Gangetic Plain region due to higher emissions and prevailing meteorological conditions. The western India shows higher particulate concentrations which are mainly dominated by dust emissions.



Simulated concentrations of PM2.5 in  $\mu\text{g}/\text{m}^3$  (Mean of May & June 2016)

### Monitoring and Assessment of Ecosystem Processes in NW Himalaya

“Monitoring and Assessment of Ecosystem Process in NWH” is a multi-institutional collaborative project of ISRO in association with Wadia Institute of Himalayan Geology, Dehradun, GB Pant Institute for Himalayan Environment and Development, Almora, Forest Departments of Uttarakhand and Himachal Pradesh States, CSK Himachal Pradesh Agricultural University, Palampur, National Institute of Hydrology, Roorkee, Snow and Avalanche Studies Establishment, Chandigarh and IISc, Bengaluru.



This research work involves a comprehensive analysis of Velocity vector for Indian and surrounding plates, determined using established CORS and campaign mode GNSS survey data. Crustal shortening across Himalaya was estimated as about 17 mm/year. Total Electron Content (TEC) data obtained from several CORS / International GNSS Stations was studied prior to the occurrence of large earthquakes in the Himalayan region, including 2015 Nepal Earthquake.

### Climate Change Induced Impacts

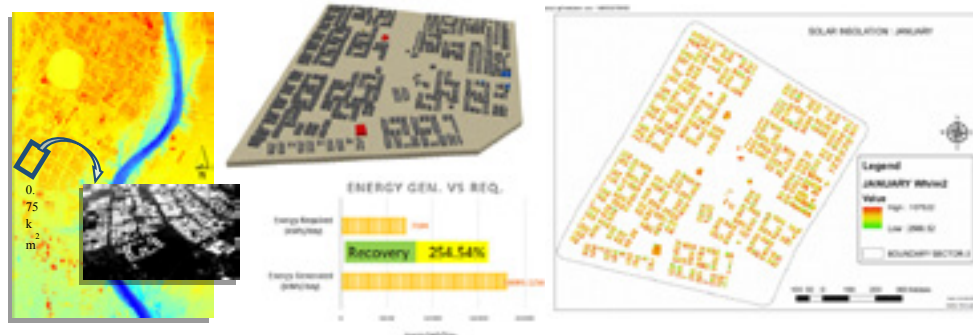
Climate change scenarios were modelled to understand the changes of Himalayan forest species. Results indicated that considerable advancement in the tree line to higher elevations and shrinking in current range distributions of temperate species.

Climate change impacts on crop productivity of major crops namely, wheat, rice and maize were simulated for 2020s, 2050s & 2080s indicated that wheat yield decline in 2020s and 2080s by 9% & 11%, respectively.

**Tree height assessment using satellite LiDAR and Optical Data:** Tree height assessment was carried out using satellite LiDAR and Optical Data (ICESat / GLAS) derived matrices and energy return from canopy. LiDAR derived matrices were related with LISS-III data to generate spatial tree height map in foot print area as well as extrapolated to the entire study area of Sundarbans.

**Retrieval of Forest Structure with Terrestrial Laser Scanner:** 3D point cloud data of individual trees were collected using ground Terrestrial Laser Scanning method. Tree parameters like dbh (diameter at breast height) and height were derived from the extracted single trees. Stem diameter and tree height were retrieved from TLS data. Above ground biomass and carbon stock of forest has also been assessed using TLS derived tree dbh and height information.

**Rooftop Solar Potential Estimation:** Geospatial analysis of rooftop solar potential estimation carried out at Gandhinagar showed that insolation is lowest in December with a value of 2.4 kWh/m<sup>2</sup> and highest in July with 178 kWh/m<sup>2</sup>. Only 30% area of available rooftops, 15% panel efficiency and 15% solar panel yield is considered while calculating energy. Building footprint map the prime input of this study were derived using high spatial resolution satellite data.



Solar Roof Top Potential Estimation



**Global Total Alkalinity and Dissolved Inorganic Carbon products:** Total alkalinity and dissolved inorganic carbon are important for understanding net CO<sub>2</sub> exchange between ocean and atmosphere. Empirical relationships exist between salinity, temperature and surface chlorophyll which can be obtained from the satellite data. This is useful to understand basin scale changes. The products are generated using salinity from Aquarius and Argos data and temperature & chlorophyll products from MODIS AQUA.

**Modeling of mean circulation in the Hooghly Estuary and adjacent Coastal Oceans:** A terrain following ocean model was used to study tide driven residual circulations, seasonal mean flow patterns and its energetics in the Hooghly estuary and adjacent coastal oceans on the northeastern continental shelf of India. The model is driven by tidal levels at open ocean end and winds at the air-sea interface. The de-tidal components of the currents were averaged for the entire period of simulation to describe residual and mean-seasonal circulations in the regions. Satellite measured Chlorophyll concentration was used along with simulated currents to describe important features of the circulations in the region.

### **Spatio-temporal Variability of Atmospheric CO<sub>2</sub> over India**

The spatio-temporal variability of atmospheric CO<sub>2</sub> over India and its surroundings based on Goddard Earth Observation System Chemical (GEOS-Chem) transport model, satellite data and in-situ observations was analysed. The model is driven by GEOS meteorological fields along with surface boundary fluxes and anthropogenic emissions from different sources. The model was executed for the period 2006-2013. The simulated CO<sub>2</sub> compared well with satellite and in situ observations. Result indicated that amplitudes of the seasonal and annual cycles are stronger over the northern hemisphere, especially over the land regions. At annual scale, the net trend of 20 TgC has resulted from balancing among different contributing factors; 380 TgC fossil fuel emission, 100 TgC biofuel emissions, 110 net terrestrial uptake and removal of 350 TgC by lateral transport.

### **Effects of Large Scale Drought on the Inter-annual Variability of Net Primary Productivity (NPP)**

Effect of large scale drought on net primary productivity (NPP) of the country based on the implementation of an ecosystem model for the simulation of monthly NPP along with surface water budget components for the years 2001-2015 was carried out. The model is driven by satellite measured normalised greenness index, climate and soil and land cover attribute maps. The remotely sensed drought severity index (DSI) computed from the monthly AET, PET and NDVI data are used to examine the consistency of meteorological drought events and its effect on the reduction of annual NPP budget of the county. The study revealed that the severe drought conditions were observed for Indo-Gangetic plain in 2005, 2007, 2009 and 2010; the Northwestern part in 2001, 2002, 2005, and 2009; Southern peninsular India in 2002 and 2003; the Eastern coastal states in 2002, 2008, 2009 and Northeastern states in 2005 and 2012 with maximum reduction of annual NPP budget of the country happening in 2002, 2009, 2011 agricultural years by 10-20% from the previous years.



## ISRO Geosphere Biosphere Programme (IGBP)

IGBP programme aims at measuring, modelling and monitoring of the biological, chemical and physical processes of the earth system, thereby also understanding the regional factors influencing the climate change. Major programmes during the reporting period include Aerosol Radiative Forcing over India (ARFI), Network of Observatories for Boundary Layer Experiments (NOBLE), National Carbon Project (NCP), Atmospheric Trace Gases Chemistry and Transport Modeling (ATCTM), Marine Carbon Nitrogen Cycles (MCNC) and Energy & Mass Exchange in Vegetative Systems. Apart from ISRO / DOS Centres, namely, NRSC, SAC, IIRS, SPL and PRL, around 70 partner institutions representing research centres and Universities across the country are also participating in these projects especially in satellite and ground based observations / analysis.

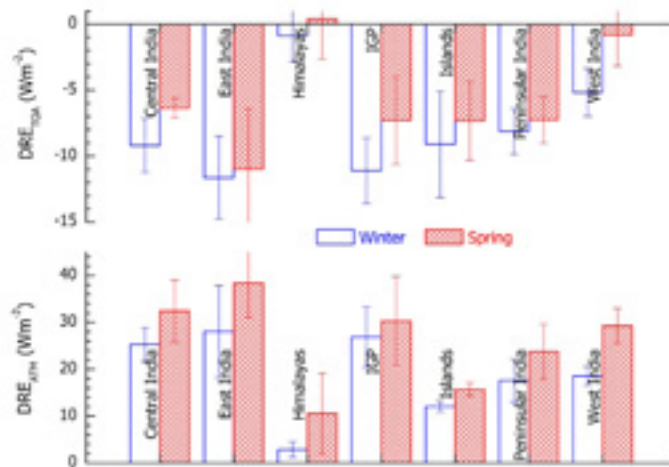
A systematic transformation of aerosols from anthropogenic to natural from winter to spring has been brought out over the Indian region using the ARFI network data. The forcing due to carbonaceous aerosols is found to be slightly negative or close to zero, indicating a cooling effect at the top of the atmosphere. Other salient observations of ARFI project include, meridional gradients in aerosol vertical distribution over Indian mainland; seasonal variation of vertical distribution of aerosol single scattering albedo over Indian sub-continent; simulation of seasonal cycle of black Carbon aerosols over India; Aerosol climatology over a high altitude Himalayan location, Hanle, etc.

As part of NOBLE project one more micro-meteorological station has been established in Ponmudi, making total number to nine. During the current year, observations were made on the effect of boundary layer circulation on regional meteorology over Northeast; Wind gust and turbulence characteristics over a mountain ridge during spring season; Impact of mountainous topography on surface layer parameters during weak mean flow conditions, etc. Some of the outcome of energy and mass exchange in vegetative systems include monthly variability of surface emitted methane fluxes over Indian agro-ecosystems and coupling with sensible heat flux; modeling of hydro-thermal surface and sub-surface fluxes in dry deciduous forest and studies on atmospheric trace gases variability and their environmental Impacts.

As part of the studies on air pollutants over the Indian subcontinent, Carbon monoxide simulation has been made for five years using MOZART model and systematically compared with MOPITT CO observations and in-situ measurements over eight Indian locations. The model showed moderate to good performance over the Indian subcontinent.

National Carbon Project (NCP) is implemented under six inter-related sub-projects namely, (i) Vegetation Carbon Pools and Dynamics (ii) Soil Carbon Pools and Dynamics (SCPD) (iii) Soil-Vegetation Atmosphere Fluxes – forests & agriculture (iv) Atmospheric CO<sub>2</sub> Retrieval and Monitoring (v) Ocean, Coastal Hydro geochemistry and fluxes and (vi) Carbon Cycle Modeling and Simulation. During the current year, a digital Terrain Model was generated for Betul, Uppangala and Achanakmar areas with 1m resolution. As part of Soil Carbon Pools and Dynamics, paired observation on CO<sub>2</sub> efflux as well as vertical distribution of soil carbon through soil profile studies have been carried out. Using the field based observations, the relationship between soil moisture, temperature, pH, SOC, etc. and CO<sub>2</sub> efflux has been studied.





**Direct Radiative Forcing (DRE) due to composite aerosols at the top of the atmosphere (TOA) and within the atmosphere (ATM) over the distinct environments over the Indian subcontinent estimated using the ground-based network of multi-wavelength radiometers under the ARFI project of ISRO-GBP**

Under the Atmospheric Trace Gases Chemistry and Transport Modeling, the observatories are equipped for the basic measurements of Ozone, CO and NO<sub>x</sub> along with weather parameters. Measurements of methane and non-methane hydrocarbons are made from the environmental labs setup/ augmented at 15 Universities / Research centres across the country. One of the experiments carried out at the Ooty site to study the effects of ozone on crops, concluded that Kufri Surya variety of potato has high resistance to ozone exposure when compared to other varieties.

### Promoting Space Technology based Tools / Applications in Governance and Development

As an outcome of Ministerial interactions and National Meet held on September 07, 2015 in New Delhi, a total of 160 space application projects have emerged across 58 Ministries / Departments in the areas of earth observation and geospatial technologies, satellite communication & navigation, meteorology, technology diffusion and capacity building. Many of the space-based applications provide valuable inputs to flagship programmes of the Government, namely, Atal Mission for Rejuvenation and Urban Transformation; Pradhan Mantri Awas Yojana; Pradhan Mantri Krishi Sinchayee Yojana; National Mission for Clean Ganga, MGNREGA and Digital India.

Out of 160 projects, about 107 projects have progressed well in terms of completion of pilots, proof of concepts, development of methodology, web based tools / mobile apps, execution of work, validation of results, etc. These projects are helping the user ministries in the utilisation of space technology towards planning, monitoring and evaluation of their activities. A few areas wherein the Ministries / Departments have been benefited by the use of space based tools / applications include, Inventory of horticulture crops and identification of suitable sites for its expansion in under-utilised regions, actionable alerts on forest loss, Monitoring & Evaluation of IWMP Watersheds, Inventory and Site Management Plans for Heritage Sites, Identifying vulnerable areas of desertification and land degradation, Geo-tagging of assets created under



MNREGA and activity monitoring, Pipeline Surveillance within Right of Usage (RoU), Island information system to enable holistic development of islands; development of inland fish / aquaculture, Rural water pipeline grid planning, etc.

Towards the execution of various space technology related projects, about 70 MoUs have been signed with Central Ministries / Departments / Agencies (46) and State Governments / Departments / Agencies (24). More than 9500 officials have been trained across various Ministries / Departments and State Governments so far..

### **State Level Meets for Promotion of Space Technology based Applications**

During the National Meet on Promoting Space Technology based Tools and Applications in Governance and Development held on September 07, 2015 at New Delhi, The Hon'ble Prime Minister also specifically suggested organising similar brain storming Meets at State level with stakeholders to promote use of space applications.

Towards this, the State level Remote Sensing Application Centre (SRSAC) set up in each State has been identified as the nodal agency for space based application related activities. Respective State Governments and SRSACs played a key role in the successful conduct of the State Meets and brought out many action plans for the development of the State using space technology.

During the last one year, 11 States have conducted their Meet, which was attended by Chief Ministers or Ministers and senior officials of State. These states are Haryana, Bihar, Uttarakhand, Mizoram, Nagaland, Rajasthan, Punjab, Jharkhand, Meghalaya, Himachal Pradesh and Kerala. Remaining States have worked out the plans to conduct such Meets.

### **Capacity Building**

Indian Institute of Remote Sensing (IIRS) is a premier institute with the primary aim to build capacity in Remote Sensing and Geo-informatics and their applications through education and training programmes at post graduate level. The Institute also hosts and provides support to the Centre for Space Science and Technology Education in Asia and The Pacific (CSSTE-AP), affiliated to the United Nations, to conduct remote sensing and GIS training and education programmes at Post Graduate level. The training and education programmes of the Institute are designed to meet the requirements of various target / user groups, i.e., for professionals at working, middle and supervisory levels, fresh graduates, researchers, academia and decision makers. The duration of courses ranges from one-week to two years. The education programmes conducted by the Institute include (1) M.Tech. course of 24 months duration in collaboration with Andhra University, Visakhapatnam and (2) M.Sc. course of 18 months duration in collaboration with the faculty of Geo-information Science & Earth Observation (ITC) of the University of Twente (UT), The Netherlands. In addition to the regular training and education programmes, the Institute also conducts 'Distance Learning Programme' since 2007, which is unique in the country complementing the education programmes of the Indian Universities.



The Institute has trained 10,512 professionals (till Oct 2015), including 983 professionals from abroad representing 95 countries from the Asia, Africa and South America. A total of 179 students in M.Sc. and 263 in M.Tech. have graduated since 2002. Special tailor-made / on-demand courses are conducted. at the request of the national and international user departments in the last few years. In addition, IIRS has also trained 1588 professionals through 44 short and 49 long-term courses from various countries in the Asia-Pacific Region in its endeavour of providing technical support to CSSTE-AP for all its RS and GIS training and education programmes.

The Institute organises two prestigious training programmes each year of 8-weeks duration under ITEC / SCAAP, namely 'Short course in RS with emphasis on Digital Image Processing (SRS)' and 'Short course in Geoinformatics (SGI), wherein a total of 507 foreigners from 95 countries have benefited. Further, 33,099 graduate and post-graduate students from 469 institutions spread across the country have also benefited through the distance learning programmes being offered by the Institute since 2007. IIRS has also launched e-learning course on Remote Sensing and Geo-information Science in August 2014.

The demand for special tailor-made / on-demand courses, conducted at the request of the national and international user departments have increased significantly in the last few years. Following special programmes were organised during current year, namely, UAV Remote Sensing (23 participants), Advanced Course on RS&GIS Applications in Forestry (12), Bangladesh Forest Range Officers on Remote Sensing and GIS Applications in Carbon Forestry (6), Geospatial Technologies for Smart City Planning (34), Remote Sensing and Geographical Information System for Geography Teachers (22), Application of GPS & GIS tools of forestry (13), Application of RS & GIS for Natural Resource Management for ISS Officers (46), Capacity Building Programme in GIS (16), Image Interpretation and RS application for Indian Air Force Personnel (14), GIS Based Utility Mapping of ISRO / DOS Campuses (33), Ortho-rectification of VHR Satellite Data (11), RS & GIS Applications in Working Plan Preparation for IFS officers (15), RS & GIS with Special Emphasis on Medicinal Plants for officials of Ministry of AYUSH (10) and SAR Applications in Geosciences for GSI officers (12). The ISRO-NCERT sponsored special course was coordinated by IIRS for conducting a special training at all India level from 25 centres simultaneously, targeting 500 PGTs of KVs, NVs and Private CBSE affiliated schools.

During 2015-16, NRSC has also trained 425 persons by organising 15 courses (One regular course, 7 Special courses, 4 Customised courses and 3 in-house training). The technical support and training in various disciplines like remote sensing, photogrammetry, microwave remote sensing and geo-informatics for various Central / State line departments, academic institutions as well as R&D institutions are being carried out regularly. In addition, five one-day 'Bhuvan overview' trainings were conducted and trained 100 participants. About 2000 participants have been trained since April 2016.

Under SAC / DECU Training & Development program, 11 in-house programs were conducted which accommodated more than 300 employees. Further, 8 educational visits were facilitated during this period and 614 students from 13 institutes benefited. 153 interns were accommodated under SAC-Academic Associate Programme.



## Space Transportation System

The Indian Space Programme has made a successful transition in terms of technology acquisition and launch vehicle development. PSLV went on to become a favoured carrier for satellites of various countries due to its reliability and cost efficiency, promoting unprecedented international collaboration. The Geosynchronous Satellite Launch Vehicle (GSLV) with indigenous Cryogenic stage, graduated to become an operational vehicle for communication satellites. Future readiness is the key to maintaining an edge in technology and ISRO endeavours to optimise, accelerate and enhance its technologies through establishment of facilities and forging partnership with industries. ISRO is moving forward with the development of heavy lift launchers, human spaceflight, reusable launch vehicles, semi-cryogenic engines, etc., to cater to different payloads and an array of missions.

### Major Accomplishments

#### Polar Satellite Launch Vehicle (PSLV)

Polar Satellite Launch Vehicle (PSLV), the Indian operational launcher, completed its thirty-eighth launch during the year. It was the thirty-seventh consecutive successful mission, further proving the reliability and versatility of this medium lift vehicle developed by ISRO. Through these launches, PSLV has demonstrated a variety of missions such as Sun Synchronous Polar Orbit (SSPO), Geosynchronous Transfer Orbit (GTO) and Low Earth orbits (LEO) thereby emerging as the workhorse launch vehicle of India.

During the year, PSLV-C32 successfully launched IRNSS-1F, the sixth satellite of the Indian Regional Navigation Satellite System (IRNSS) on March 10, 2016 from Satish Dhawan Space Centre SHAR.

PSLV-C33 successfully launched IRNSS-1G, the seventh satellite in the IRNSS on April 28, 2016 thus completing the IRNSS constellation (NavIC). IRNSS-1G Satellite weighing 1425 kg was precisely injected to an elliptical sub GTO of 284 Km X 20,657 Km. 'XL' version of PSLV was used for PSLV-C32 and 33 missions.



PSLV-C34 Lifts-off



Later, PSLV-C34 successfully launched Cartosat-2 Series Satellite along with nineteen small satellites on June 22, 2016. Nineteen small satellites included two national student nano satellites, namely, SATHYABAMASAT from Sathyabama University, Chennai and SWAYAM from College of Engineering, Pune and seventeen foreign satellites, namely, one micro satellite and twelve nano satellites from United State of America, one micro satellite and one nano satellite from Canada and one nano satellite each from Germany and Indonesia. The XL version of PSLV was used to launch the satellites. For flexibility to mount multiple satellites, a novel gridded version of Dual Launch Adaptor (DLA-V4) and Multiple Satellite Adapters were designed and developed. After injecting the satellites, the upper stage of PSLV (PS4) was restarted twice for 4 seconds each to demonstrate the onboard guidance algorithm, management of PS4 stage control, thermal conditioning, tracking and visibility, which is needed for injecting multiple satellites into different orbits.

PSLV-C35 in the Generic configuration successfully launched SCATSAT-1, a weather satellite into a 720 km Sun Synchronous Orbit at an inclination of 98.1 deg to the equator on September 26, 2016. Seven co-passenger satellites were also launched in this mission, which included two national student nano satellites namely, PISAT from PES Institute of Technology, Bengaluru and PRATHAM from IIT, Bombay and five foreign satellites, namely, two micro satellites and one nano satellite from Algeria and one nano satellite each from Canada and United States of America. In this mission, after injecting SCATSAT-1 satellite, the upper stage of PSLV (PS4) was restarted twice for 20 seconds each to meet the orbit requirement of the remaining satellites. This was the longest mission of PSLV spanning around 8000 seconds.

### Geosynchronous Satellite Launch Vehicle (GSLV)

Geosynchronous Satellite Launch Vehicle (GSLV) is a three-stage vehicle with solid, liquid and cryogenic upper stage, designed to place 2-ton class of communication satellites in Geosynchronous Transfer Orbit (GTO).

GSLV-F05 with indigenous Cryogenic Upper Stage (CUS), successfully launched INSAT-3DR, an advanced weather satellite of 2,211 kg, into GTO on September 08, 2016, from the Second Launch Pad of SDSC, SHAR, Sriharikota. The satellite was precisely placed in its pre-determined GTO orbit. GSLV-F05 mission further demonstrated the reliability of CUS engine and the stage developed by ISRO. This was the tenth flight of GSLV and the fourth flight to use the indigenous Cryogenic Upper Stage. The last three GSLV flights have been consequently successful with indigenous Cryogenic stage. This launch signified a major step in perfecting the highly complex cryogenic propulsion technology and also achieving self-reliance in launching 2 ton class communication satellites into GTO.



**GSLV-F05 carrying INSAT-3DR Lifts-off**



The realisation of subsystems / stages for the next flight GSLV-F09 has commenced. Main Engine has been integrated and acceptance hot test have been completed successfully. Realisation propellant tanks and stage structures are completed and integration activities are in progress. GSLV-F09 carrying GSAT-9 satellite, is targeted for launch by March 2017.

### Geosynchronous Satellite Launch Vehicle Mark III (GSLV-Mk III)

GSLV-Mk III is the next generation launch vehicle of ISRO capable of launching 4 ton class of satellites to Geosynchronous Transfer orbit (GTO). It is a three stage vehicle with two solid motor strap-ons (S200), a liquid propellant core stage (L110) and a cryogenic stage (C25). The solid motors and liquid propellant core stage were successfully flight tested in the sub-orbital GSLV-Mk III X-mission during December 2014. This flight validated the vehicle design for the crucial and complex atmospheric flight regime and the stage separation systems. Post Flight Analysis (PFA) of GSLV-Mk III X-mission proposed changes in vehicle configuration to improve aerodynamic robustness and reduce the acoustic level. The changes in heat shield from bulbous to ogive and slanted nose cone for S200 strap-ons have been implemented and will be validated in GSLV-Mk III-D1 flight. In addition to above changes, grain configuration of head end segment of S200 motor was modified to reduce the peak dynamic pressure on the launch vehicle during atmospheric flight regime. To validate the changes in S200 Head End Segment grain configuration, a static test of S200 (ST-03) was successfully conducted on June 14, 2015. Significant achievements were also made in the development of high thrust cryogenic CE20 engine. Integrated Engine (E1) development test at sea level conditions were completed with the successful accomplishment of 12 tests, which validated the structural integrity of engine systems and demonstrated the repeatability of engine performance. Two cold flow tests and 10 hot tests including one flight duration hot test for 635 seconds and one extended duration hot test for 800 seconds were carried



CE20 Engine mounted inside HAT Facility



out. Further, two CE20 engines (E2 & E3) have been successfully realised. E2 engine has undergone successfully three hot tests for durations of 7s, 30s and 640s before it is integrated to C25 development stage for stage level hot tests. E3 engine has undergone successfully four hot tests under vacuum condition simulating flight conditions and engine ignition sequence has been finalised. After completion of acceptance test for medium duration, E3 engine will be integrated to C25 flight stage to power the upper stage of GSLV Mk-III during its first development flight GSLV-Mk III-D1. The first functional C25 stage was successfully realised. This stage has been identified for ground hot test and propellant and draining trials at launch pad. The stage has been positioned at SDSC-SHAR and preparations for propellant mock-up are in progress. Propellant Casting of S200 middle segments for GSLV-Mk III-D1 had been completed. Two S200 motors have been fully integrated at SDSC-SHAR. L110 stage assembly has been completed at IPRC, Mahendragiri. Realisation of C25 stage is in advanced stage, propellant tanks are realised and stage integration is in progress. The first hardware for ogive payload fairing has been realised and successfully acoustic tested. The launch of GSLV-Mk III-D1, the first developmental flight carrying GSAT-19 satellite of mass 3,200 kg, is targeted during the first quarter of 2017.

### Semi-cryogenic Project

The semi-cryogenic Project envisages the design and development of a 2000 kN semi-cryogenic engine for a future heavy-lift Launch Vehicle. The semi-cryogenic engine uses a combination of Liquid Oxygen (LOX) and ISROSENE (propellant-grade kerosene), which are eco-friendly and cost-effective propellants. Turbo pump systems of semicryogenic engine, namely. Low Pressure Oxidiser Turbo pump (LPOT), Low Pressure Fuel Turbo pump (LPFT) and Main Turbo Pump have been realised. Cold flow tests (nine tests) for LPOT and cold flow tests (two tests) for Low Pressure Fuel Turbo Pump (LPFT) were conducted successfully. Further tests for LPFT and Main Oxidiser Pump (MOP) are in progress at Cold Flow Test (CFT) facility at IPRC, Mahendragiri. The test configuration of boot strap mode hardware and thrust chamber at de-rated condition were finalised and generated the 3D model. Preliminary details of overall Stage configuration and stage engineering of Semi-cryo stage with 200 T propellant loading (SC 200) has been worked out.



Semicryo LPFT

### Reusable Launch Vehicle – Technology Demonstrator (RLV-TD)

A winged Reusable Launch Vehicle Technology Demonstrator (RLV-TD) has been configured to act as a flying test bed to evaluate critical technologies such as hypersonic aero-thermodynamic characterisation, autonomous navigation, guidance & control and reusable thermal protection system.

The first experimental mission towards the realisation of fully reusable launch vehicle i.e., RLV-TD was successfully conducted on May 23, 2016 from the First Launch Pad of Satish Dhawan Space Centre,



Sriharikota. The 6.5 m long winged body RLV-TD was initially carried by a special solid rocket booster up to an altitude of 49 km, where it was separated. After separation from the booster rocket, the vehicle climbed further up to an altitude of 69 km, and then had a controlled descent through the dense atmosphere and finally glided into the sea after simulating the landing manoeuvres. The total flight duration was 770 seconds from lift-off to touch down in the Bay of Bengal, approximately 450 km from Sriharikota. The vehicle was successfully tracked during its flight from the ground stations at Sriharikota and a ship borne terminal. With this flight, critical technologies such as autonomous navigation, guidance & control and reusable thermal protection system have been successfully demonstrated along with new technologies like carbon-carbon nose cap, hot structures and Lithium ion batteries. The success of this mission along with the demonstration of robustness of autonomous mission management now gives confidence to pursue further developmental activities in the area of winged re-entry vehicles.



RLV-TD Lift-off

### Critical Technologies for Human Spaceflight Project

The objective of Human Spaceflight Programme is to undertake a human spaceflight mission to carry a crew of two to Low Earth Orbit (LEO) and return them safely to a predefined destination on earth. The programme is proposed to be implemented in phases. Critical technologies that are needed to undertake human spaceflight are Crew Module (CM) System, Crew Escape System (CES) and Environmental Control and Life Support System (ECLSS). The crew module was successfully flight tested in the GSLV MkIII-X / CARE mission in December 2014.

The performance demonstration test of Crew Escape System (CES) has been planned through Pad Abort Test (PAT) flight. PAT flight demonstrates the capability of CES to execute a ground based abort in case of an exigency at launch pad. In PAT flight, the test article (consisting of CM and CES) with a height of 14 m and lift-off mass of 12.5 t, is propelled at an acceleration of 10 g with the help of quick acting solid motors. Upon reaching a safe altitude and range, the crew module separates and safely lands in sea with the help of parachute based deceleration system. To enable quick acting, special purpose solid motors with high-burn rate propellant (being developed for the first time) and special features like reverse flow multiple nozzles and canted nozzles with scarfing have been designed and realised. Proof pressure test and propellant casting for motors have been completed. Facilities for vertical testing of solid motors and launch pedestal for PAT flight are being realised at SDSC. Wind tunnel tests for CES configurations have



Low-altitude Escape Motor



been completed. Crew Module (CM) structure required for CES test has been realised and successfully structural tested. The Pad Abort Test is expected to be completed by March 2017.

For demonstrating the Environment Control and Life Support System (ECLSS), integrated tests of Temperature & Humidity Control System (THCS) involving Air-Liquid Heat exchangers, Liquid-Liquid heat exchangers, pumps, space radiator, sensors and other accessories were successfully carried out. Preliminary ground based circuit for Cabin Pressure Control System (CPCS) was developed and realisation is in progress. A ground based Personal Hygiene Management System (PHMS) was configured and an engineering model has been realised.



**Structural Test of Crew Module**

### **Air Breathing Propulsion Project (ABPP)**

Air Breathing Propulsion Technology is another important step which enables significant reduction in lift-off mass by eliminating the need to carry the oxidizer there by reducing the cost of launch vehicle and substantial improvement in payload fraction. The first experimental mission towards the realisation of Hypersonic Air Breathing Propulsion System, i.e. Scramjet Engine was successfully conducted on August 28, 2016 from Satish Dhawan Space Centre, Sriharikota. For the demonstration of supersonic combustion in hypersonic flight, two Scramjet engines were mounted on the two stage solid rocket booster. Supersonic combustion was established in the Scramjet engines with simultaneous auto ignition. The important flight events, namely, burn out of booster rocket stage, ignition of second stage solid rocket, ignition and combustion in both engines for a duration of 14 and 18 seconds respectively and followed by burn out of second stage took place exactly as planned. After a flight of about 300 seconds, the vehicle touched down in the Bay of Bengal, approximately 325 km from Sriharikota. With this flight, critical technologies such as supersonic ignition of air breathing engines, air intake mechanism and fuel injection systems have been successfully demonstrated. Experimental data from this mission will serve as a useful input for the development of an Hypersonic Air Breathing Propulsion System. Success of Scramjet Engine Technology has given confidence to undertake long duration Scramjet missions in the future.



**Scramjet Technology Demonstrator on its launcher**



## Advanced Technology Vehicle and Sounding Rocket

Advanced Technology Vehicle (ATV) is a low cost sounding rocket platform for conducting atmospheric experiments as well as provides a cost effective platform for testing the airworthiness of new subsystems, new avionics packages and new technologies before introducing into launch vehicles. ATV-D02 was successfully launched on August 28, 2016 from SDSC carrying twin Scramjet air breathing engines for supersonic combustion experiment. The rocket systems performed as desired by providing peak Mach No.6 and dynamic pressure of 148 KPa conditions for the supersonic combustion.



ATV-D02 Nosecone Payload

## Sounding Rockets

Total of ten RH-200 rockets were successfully launched during year from TERLS range. So far 122 successive successful launches of RH-200 rocket launch have been conducted from TERLS, VSSC.

RH-300 Mk II rocket and Telemetry payload subsystems are realised and harnessing has been completed for launching Space Physics Laboratory (SPL) scientific payloads.



RH-200 Launch

## Indigenisation

Ti5Al2.5Sn-ELI alloy gas bottle, ignition resistant metal-ceramic coating, high voltage programmable power supplies, 1W catalyst bed heater, Cryogenic bearing (dia. 35mm) for CE20 engine, LH2 and LOX propellant acquisition system, High strength and corrosion resistant steel as an alternative to AISI 440C grade steel for bearing application and CUS umbilical were indigenised during the year.

## Infrastructure

Major infrastructure facilities / equipment that were realised during the current year are:

Advanced Thermo vacuum Test Facility, Nozzle testing facility, 1000 T hydraulic press, Neutron radiography facility, Hot Isostatic Press facility, Structural Test Facility, Semicryo flow control Components Assembly and Test (SCAT) facility, Semicryo Turbopump Bearing and Seal Lab, CADD Facility, Vacuum furnace for silicide coating and Mobile Multi-Object Tracking Radar (MOTR) facility.



## Space Sciences and Planetary Research

Space science research in India is witnessing its golden era with Mars Orbiter Mission in its extended life time and AstroSat, the first Indian multi-wavelength astronomy mission completing its first year in orbit. Several new results and improved high resolution images of Mars have brought appreciation from scientific community all over the world. The Indian space programme is now engaged in developments for its future space science missions like Chandrayaan-2 and Aditya-L1.

Space science research activities at par with international scenario are continuously being pursued at premier research laboratories of ISRO / DOS, namely, Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), Space Physics Laboratory (SPL) at VSSC, Space Astronomy Group at ISAC and feasibility studies are undertaken in several ISRO Centres.

Recognising the significance of empowering basic research in space sciences across the country, novel research projects in the field of atmospheric science, astronomy and planetary exploration are supported at various universities and research institutes. Interested scientists from various research institutes are encouraged to undertake space instrument / payload development with ISRO funding support, based on the recommendations of Advisory Committee for Space Science (ADCOS).

The major activities carried out under space science and planetary research during 2016-17 are summarised below.

### MARS ORBITER MISSION

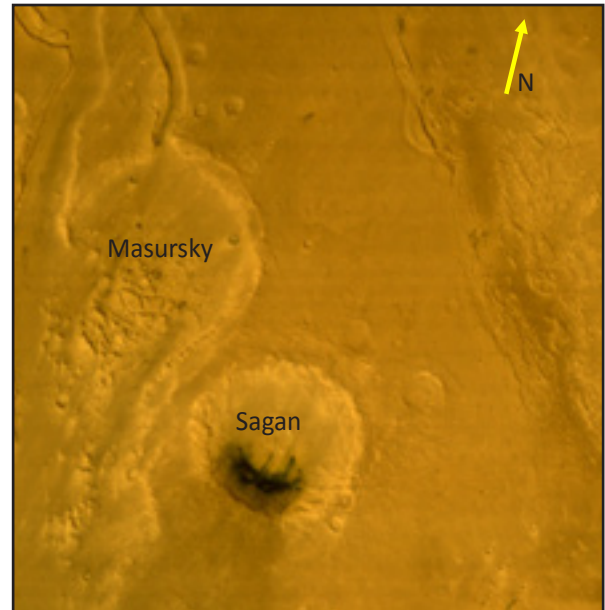
Mars Orbiter Mission (MOM), India's first interplanetary mission to planet Mars, launched on November 05, 2013, completed two years in its orbit around Mars on September 24, 2016. MOM is on an extended mission after completing six months of designed mission life in its orbit. At present MOM and all its scientific payloads are in good health and it continues to provide valuable data of Mars surface and its atmosphere. The increased duration of observation of Mars by five scientific payloads is enhancing the planetary science data and also enabling coverage of Mars in different seasons.

Scientific analysis of the data received from the Mars Orbiter spacecraft is in progress. Sixteen scientific papers have been published in peer reviewed journals. The Mars Colour Camera, one of the scientific payloads onboard MOM, has produced more than 590 images so far. Some of the processed images taken by MCC follow.





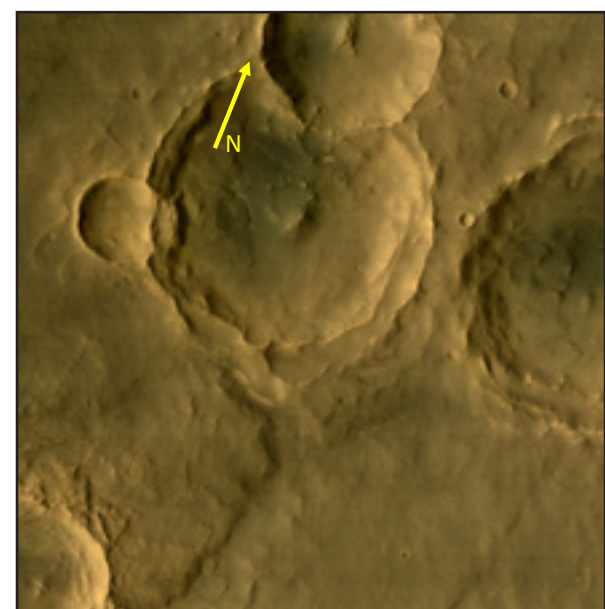
Flammarion Impact Crater situated at Indus Vallis  
(July 10, 2016)



The Masursky and Sagan Craters on Mars  
(September 16, 2016)



Danielson and Kalocsa Craters on Mars  
(September 24, 2016)

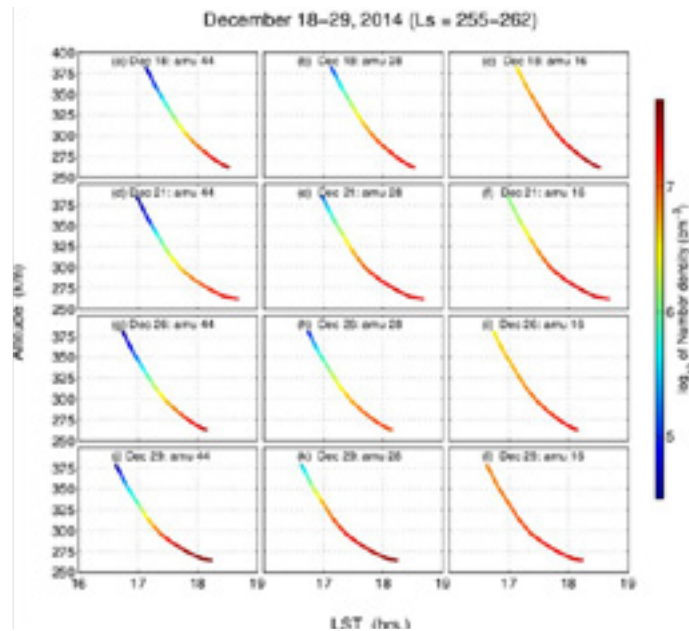


Coprates region of Mars  
(November 23, 2016)

### Sample Images from MCC Captured during 2016

The in-situ measurements of the composition of the low-latitude Martian neutral exosphere were carried out by Mars Exospheric Neutral Composition Analyser (MENCA). Observations by MENCA have shown that the abundance of Oxygen exceeds that of Carbon Dioxide at an altitude of  $\sim 270 \pm 10$  km during Martian evening.





**Number Density Variation of the Major Constituents ( $\text{CO}_2$ ,  $\text{CO+N}_2$ , O) of Martian Exosphere, during four Periapsis Passes of MOM**

These are the first in-situ measurements of composition during the local dusk sector on Mars, which would help in setting up the boundary conditions for models dealing with thermal escape processes. The models are basically used to understand the evolution of Martian atmosphere to its present state and its response to various forcings.

An announcement of opportunity was made for proposals to expand the scientific community within the country in order to access and analyse MOM data and 28 proposals were selected for funding support.

On the occasion of two year completion, of Mars Orbiter Mission, ISRO released the first year (Sept 2014 to Sept 2015) data sets to the public through ISSDC website. 1,100 users registered till December 2016 and downloaded about 200 Gb data.

## AstroSat Mission

The Indian multi-wavelength space astronomy observatory AstroSat has completed one year in orbit on September 28, 2016. Several celestial sources have been observed and studied in detail. The results obtained are excellent and are being published. The satellite is functioning normally and all the state-of-the-art world-class payloads are being operated.

AstroSat observes the universe in limited optical, near and far Ultraviolet and X-ray regions of the electromagnetic spectrum. The uniqueness lies in the simultaneous multi-wavelength capability using a single satellite. These can further be extended to co-ordinated observations using other spacecraft and ground based observatories.



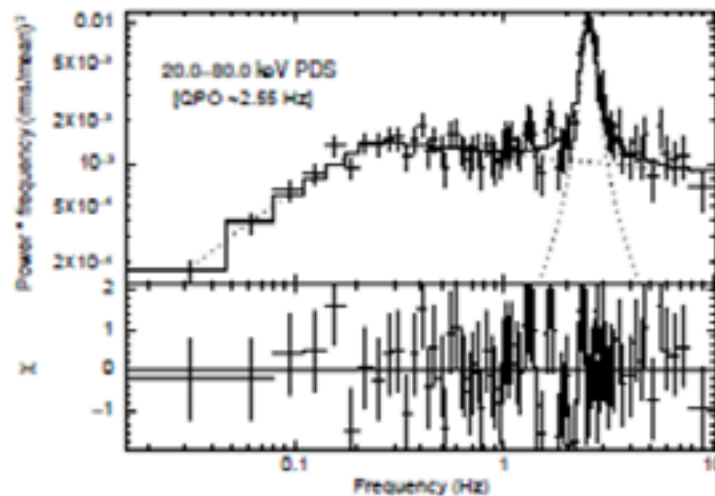
The effective area of Large Area X-ray Proportional Counter (LAXPC) is  $\sim 6000 \text{ cm}^2$  @ 5-20 keV. The LAPEX has three to four times the effective area of Rossi X-ray timing Explorer (RXTE) above 20 keV. It is the only instrument for fast timing studies during this timeframe.

Image resolution of UVIT is  $\sim 1.5''$  in near UV compared to  $\sim 6''$  of Galaxy Evolution Explorer (GALEX) mission. UVIT is one of the best UV telescopes with very good position resolution and large Field Of View (FOV) of about half a degree, in both FUV and NUV bands.

The first six months dedicated for performance verification and onboard calibration of payloads indicated that the performance of all the payloads conformed to the design parameters. April to September 2016 during which science observations were done, was provided as guaranteed time for the payload teams. Currently, AstroSat is operating as an observatory, in which the observatory time is allotted to proposers from India, in addition to the payload teams.

Some of the salient science observations are:

1. LAPEX has observed for the very first time rapid variability of high energy (particularly  $>20\text{keV}$ ) X-ray emission from a black hole system, GRS 1915+105.



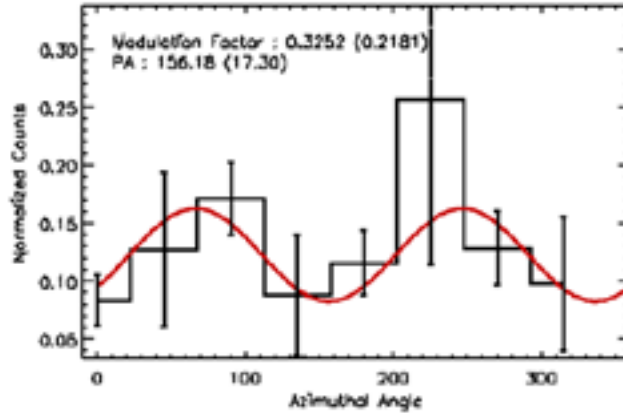
**Power density spectrum for the source GRS 1915+105. As seen in the figure, Quasi periodic oscillations (QPOs) at 2.55 Hz are observed in the energy band 20 – 80 keV for the first time. This QPO changes in frequency as the flux of the source changes.**

LAXPC, also measured the arrival time difference between the high and low energy X-rays (which is of the order of tens of milli-seconds) providing direct clues to the geometry and dynamic behavior of the gas swirling around a spinning black hole (Ref: arXiv:1608.07023 [astro-ph.HE]). A publication based on the above results is accepted in Astrophysical Journal.

2. The Cadmium Zinc Telluride Imager (CZTI) normally operates in the energy range 15 – 100 keV. At higher energies, the FOV of this imager becomes wide and therefore it can detect Gamma Ray Bursts (GRBs) which are transient gamma ray events that can occur at any time in any



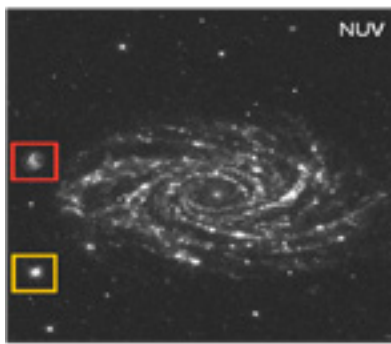
part of the sky and are considered to arise at cosmological distances. CZTI has detected over 40 Gamma Ray Bursts (GRBs). CZTI has demonstrated capability to detect polarisation in GRBs.



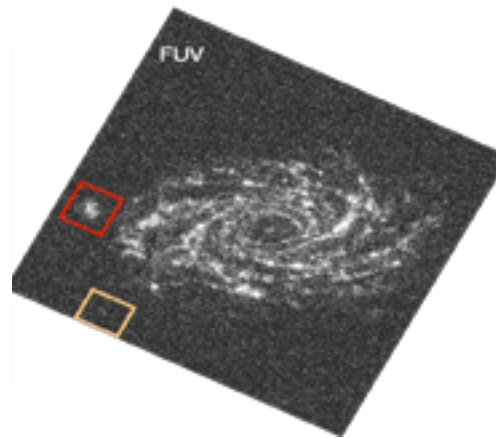
Identified events corrected for geometry contributing to the GRB 1510016A (in black) as a function of azimuthal angle. The red solid is the fit to the modulation curve. The fitted modulation factor is 0.32 with the detection significance of 1.5

Further details of the results have been accepted for publication in Astrophysical Journal. For reference, see arXiv:1608.07388 [astro-ph.HE]. Polarisation properties and their relation to the spectral evolution have the potential to distinguish between various models of GRB prompt emission mechanism.

3. Ultraviolet Imaging Telescope (UVIT) observed the field stars in the open cluster NGC 188. One source which was earlier thought to be a sub-dwarf is found to be a binary with sources having temperatures around 12500 K and 5750 K. The galaxy NGC 2336 was imaged on December 17, 2015. The image is one of the best resolved, large field near and far UV image of this galaxy and its surroundings, at present.



Faint galaxy (red box) and the bright star (yellow box) are clearly visible in near UV

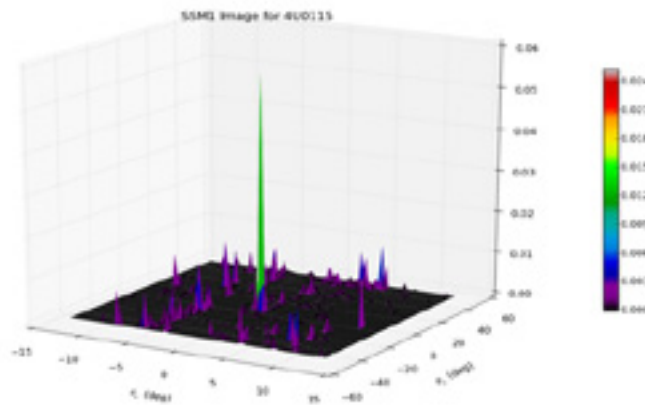


In FUV, only the hotter stars / objects get detected. Though the galaxy is faint (red box) it has hot stars and detected in FUV image. The bright star (yellow box) is hardly visible since it is a cool star.

**NGC 2336 observed by UVIT in near and far UV**

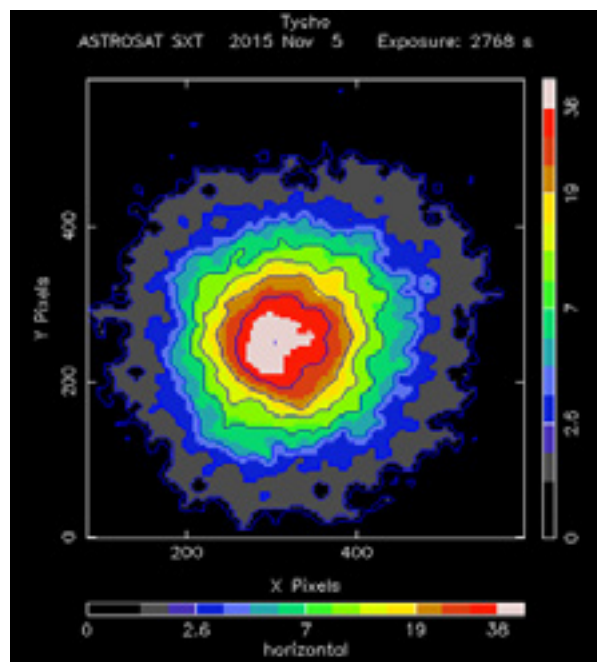


4. Scanning Sky Monitor (SSM) observed the X-ray pulsar 4U0115+63 in its outburst phase and the pulsations of 3.6 seconds were detected.



**SSM Image for the X-ray Pulsar 4U0115+63**

5. Soft X-ray Telescope (SXT) detected the continuum and lines from bright Supernova Remnant such as Tycho. The advantage of having a good spectral resolution along with large field of view is expected to be extremely important to study the clusters of galaxies.



**SXT Image of the Tycho Supernova Remnant**

The AstroSat Support Cell (ASC) was formally dedicated by Chairman, ISRO to the scientific community on the occasion of one year completion of AstroSat.



## CHANDRAYAAN-2 Mission

The Chandrayaan-2 mission is the next step of ISRO to reach, land and explore the Moon. The Chandrayaan-2 spacecraft is a composite module consisting of Orbiter, Lander and Rover. Unlike Chandrayaan-1, where Moon Impact Probe (MIP) crash landed on the surface of the Moon, Chandrayaan-2 will soft land its Lander with Rover on the Lunar surface to conduct next level of scientific studies. Many new technologies are being developed indigenously to achieve the mission requirements. The Chandrayaan-2 is planned to be launched by GSLV MkII launch vehicle during first quarter of 2018.

### Orbiter Craft

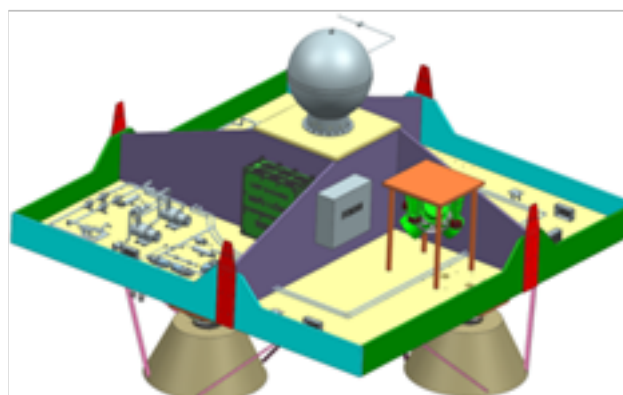
Primary structure of Orbiter Craft has been realised. Fabrication of panels is in progress. Configuration of mainframe systems and payloads was completed. Integration of mainframe systems including propulsion elements was expected to commence from December 2016. Payloads from various centres are in advanced stages of realisation and expected to be delivered in first quarter of 2017 for integration.

### Lander Craft

Lander configuration is finalised to meet the soft and safe landing at the identified site. Payload configuration and interfaces with lander are finalised. Engineering models of mission critical sensors, namely, Ka-Band Radio Altimeter (KaRA) and Lander Pattern Detection Camera (LPDC) from SAC and Laser Inertial Reference & Accelerometer Package (LIRAP) from IISU have been realised and performance tested in Lander Sensor Performance Test (LSPT), Phase-1 over artificial craters created, at Chitradurga in Karnataka. System Demonstration Module (SDM) realisation for evaluating the performance of Lander propulsion system with throttlable engines, Lander Actuator Performance Test (LAPT) configuration and Lander electrical packages required for LAPT are in advanced stage of completion. Engineering model of Lander Leg was realised and single leg drop tests were completed. A facility has been established at Lunar Terrain Test Facility for conducting lander leg drop tests.



Crater created at Chitradurga District



LAPT Configuration



## Rover

All the rover flight systems are in advanced stage of realisation. Soil mixing exercise is completed and the mobility test to evaluate the Rover's wheel – soil interaction is under progress.

## Aditya - L1 Mission

The original Aditya - L1 mission was conceived as a small satellite in a ~800km orbit carrying one payload to study solar corona. The mission has been enhanced and termed as Aditya-L1 mission carrying seven payloads, which was approved in 2015. It is scheduled for launch during 2020 timeframe by PSLV-XL.



Rover undergoing tests at Lunar Terrain Test Facility

Aditya-L1 can provide observations on the corona and in addition can provide observations on the solar chromosphere using an UV payload and on the photosphere and flares using X-ray payloads. These payloads taken together are expected to provide a comprehensive understanding of how solar flares originate and propagate. In addition, the charged particle detectors and the magnetometer payloads can provide information on charged particles and the magnetic field which emanate from the eruptive events. To enable this, the Aditya-L1 spacecraft is to be placed in a halo orbit around the Sun-Earth Lagrangian point 1 (L1) which is about 1.5 million km from the Earth.

Baseline Design Review (BDR) for all the mechanisms is completed. MoUs were signed with IIA and IUCAA for the development of Visible Emission Line Coronagraph (VELC) and Solar Ultraviolet Imaging Telescope (SUIT) payloads. Design and development of all the payloads are in progress. The Preliminary Design Review (PDR) is expected to be completed by December 2016.

## X-ray Polarimeter Satellite (XPoSat) Mission

Imaging, timing and spectral studies are being carried out by various X-ray satellites, but X-ray polarisation studies of celestial objects has been minimal. The X-ray Polarimeter Satellite (XPoSat) mission is the first dedicated mission for polarisation studies and was approved in April 2016. Polarimeter Instrument in X-ray (POLIX) payload will study the degree and angle of polarisation of bright X-ray sources in the energy range 5-30 keV. Payload development is in progress at Raman Research Institute (RRI), Bengaluru.

QM mechanical components (detectors and collimator) are ready. Electronic packages are under fabrication. Prototype of Be / Li scatterer is under development at BARC.

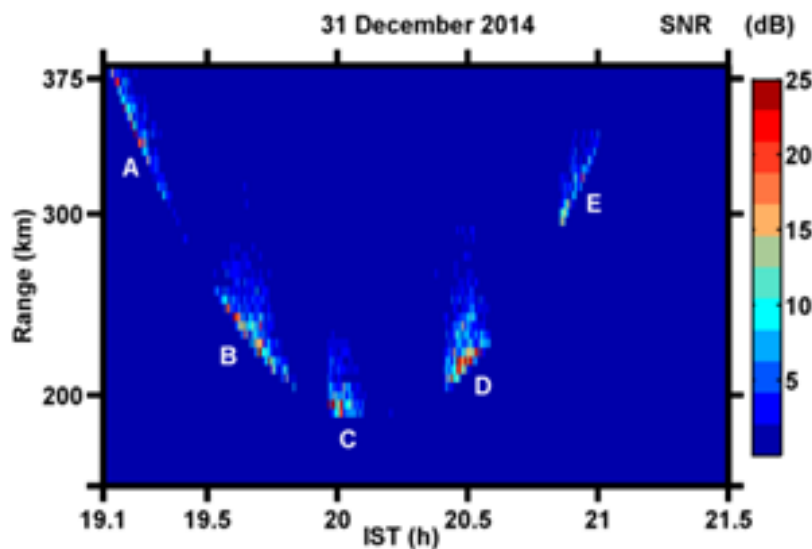


## RESEARCH ACTIVITIES IN SPACE SCIENCES

The National Atmospheric Research Laboratory (NARL) at Gadanki near Tirupati, an autonomous society supported by DOS, is pursuing atmospheric research with the vision “Developing capability to predict the behavior of the atmosphere through observations and modeling” which includes technology development, observations, data archival, dissemination, assimilation and modeling and encourages national and international scientists to utilise the facilities for front ranking research in atmospheric and space Sciences ([www.narl.gov.in](http://www.narl.gov.in)).

Some of the important studies during this year are as follows:

1. The high-power-large-aperture MST radar established at NARL has been successfully employed to detect the moon echoes, providing opportunity of probing planetary bodies, a new dimension of future research activities from NARL. The detection of moon echoes also provides an important means to characterise the large phased array antenna system including the calibration of the radar. Example of moon echoes observed in different directions, in the form of range-time variations of Signal-to-Noise Ratio (SNR) is shown in the Figure.



SNR of moon echoes as a function of ambiguous-range and time observed in different beams. True range  $\hat{=}$  Observed range + 367740 km. Echoes marked as A, B, C, D, and E correspond to observations made in the East-18°, East-12°, East-6°, Zenith, and West-6° beams, respectively.

2. Using 13 years (April 2002 to December 2014) of Broadband Emission Radiometry (SABER / TIMED) 1.6  $\mu\text{m}$  OH airglow emission data, the long-term variation of OH peak emission altitude and Volume Emission Rate (VER) over Indian Low Latitudes was studied. It is found that the altitude at which the OH peak emission occurs was found to be varying during both day and night time and showed a small negative trend (-30 m/year) over the low latitude.

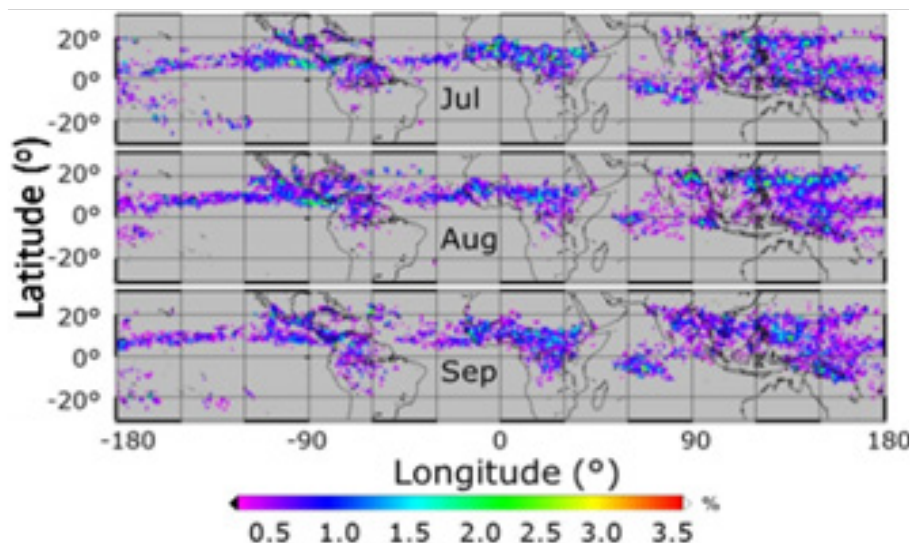


3. A study on the variations of cloudiness and its relation with Sea Surface Temperature (SST) using space borne imagers showed a general pattern of increase in cloudiness with SST in the range of 26 to 28 deg C.

The Space Physics Laboratory (SPL) at VSSC primarily focuses in the research areas of Atmospheric, Space and Planetary sciences. Studies using MENCA onboard MOM are continuing.

Some of the major studies during this year are as follows:

1. Using S-band observations from Chandrayaan-1 and a photochemical model, the presence of a plasma density of about  $300 \text{ cm}^{-3}$  near the lunar surface, its monotonical decrease with altitude, and its molecular nature of origin was brought out. The observations from SARA experiment onboard Chandrayaan-1 revealed the presence of new populations of protons in lunar plasma wake, which is not explainable by the known mechanisms.
2. A systematic transformation of aerosols from anthropogenic to natural from winter to spring has been brought out over the Indian region using the ARFI network data which also indicates that forcing due to carbonaceous aerosols is found to be slightly negative or close to zero.
3. A methodology to derive tropical Deep Convective (DC) cloud core with cloud top altitudes from MT-SAPHIR data has been developed and the global distribution of occurrence frequency of DC clouds and their spatio-temporal variation is studied. The large vertical gradient in water vapour mixing ratio in the tropical tropopause layer has been brought out from the frost-Point Hygrometer balloon campaign.



Occurrence frequency [%] of overshooting clouds (highest altitude, that can reach beyond tropopause, for July (top panel) to September (bottom panel) 2012 derived from Megha-Tropiques SAPHIR Tb data over the tropical region.



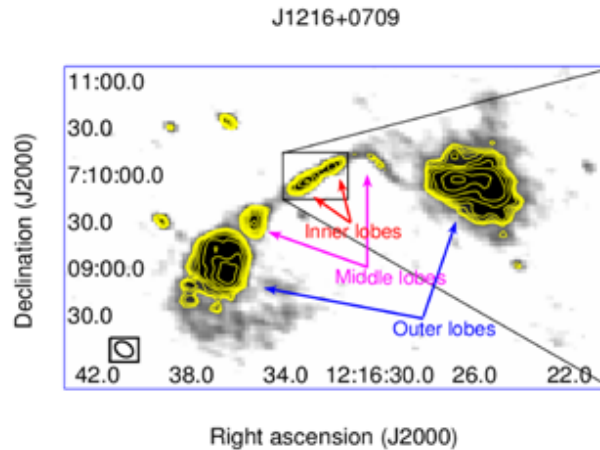
4. First observational evidence for the role of meteoric activity in the generation of the Equatorial Counter Electrojet (CEJ) has been obtained. A comprehensive mechanism based on Equatorial Temperature and Wind Anomaly is proposed for the generation and evolution of F3-layer.
5. The development of payloads for Chandrayaan-2 mission and Aditya-L1 mission are progressing well. Under the ISRO's national projects GBP and NOBLE, a 25-m tower at NRSC, Hyderabad, and a 10 m tower at IIST, Ponmudi, has been installed, in addition to the commissioning of an aerosol observatory at Ponmudi.

The Physical Research Laboratory (PRL) at Ahmedabad is an autonomous unit of DOS and a premier research institute engaged in basic research in the areas of Astronomy and Astrophysics, Solar Physics, Planetary Science and Exploration, Space and Atmospheric Sciences, Geosciences, Theoretical Physics, Atomic, Molecular & Optical Physics and Astrochemistry.

Some of the important studies during this year are as follows:

1. Clear imprint of equatorial electrodynamics has been revealed in neutral optical oxygen dayglow emission variability over low-latitudes. A systemic behavior between those two seems to exist as a function of solar activity revealing the ion-neutral coupling in the upper atmosphere.
2. Long term observations of OH and O<sub>2</sub> nightglow emission measurements obtained by an in-house built near infrared spectral imager revealed the solar activity dependence of mesospheric density variations.
3. Evidence for prompt electric field disturbance driven solely by changes in the solar wind density under Northward IMF Bz condition has been obtained for the first time.
4. Data analysis and modeling of Mars atmosphere indicate that within the Alba Mons region, the extent of glaciation has been very extensive. These and earlier results provide significant constraints for deciphering past cold climatic conditions and suggest that multiple glacial episodes of varying extent.
5. First model results for dust densities and electron densities in the D region ionosphere of Mars and aerosol particles of different sizes during a major dust storm at low latitudes have been reported.
6. A rare galaxy has been discovered using the Giant Metrewave Radio Telescope (GMRT), where the Super Massive Black Hole SMBH at its Centre appears to have undergone three cycles of jet activity. Till date, there are only two such galaxies known in the Universe and this is only the third known galaxy of its kind.





**The GMRT 610 MHz image of J1216+0709 displaying three pairs of radio lobes namely inner, middle, and outer. The three pairs of lobes are believed to be the result of three different episodes of AGN activity.**

7. Surface Active Substances (SAS) were measured over an urban environment to evaluate their effect on cloud droplet formation. A significant amount of SAS were observed which can reduce surface tension of the droplet, and can facilitate droplet formation by lowering the critical super saturation. Results from real time measurement of aerosol ionic constituents and gas phase  $\text{NH}_3$  over an urban location in west coast of India, suggest that  $\text{NH}_3$  is the dominant neutralising species for acidic components such as  $\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$ .
8. A new class of coherent sources based on cubic phase modulation of a singly-resonant Optical Parametric Oscillator (OPO) have been reported for an Airy beam. The first ultrafast Airy beam OPO that can be tuned continuously from 1477 to 1727nm, providing an average power as much as 306mW at 1632nm in pulses of  $\sim 23$ ps duration with a spectral bandwidth of 1.7nm has also been realised.
9. Dark Matter (DM) in Earth intersecting orbits can scatter off the electrons and lose energy, and finally be gravitationally bound to Earth and eventually, lose enough energy and accumulate at the core. It is assumed that DM annihilates / decays predominantly into Standard Model particles inside Earth. The heat flux from these processes is compared with the experimentally measured value of internal heat flux of the Earth which is 44 TW. Assuming steady state between capture and annihilation / decay, constraints were put on the scattering cross section of DM with electrons as a function of their mass. For low mass regions ( $<0.01\text{GeV}$ ), these constraints on leptophilic DM are better than the ones obtained from direct-detection experiments.
10. The development of payloads for Chandrayaan-2 mission and Aditya-L1 mission are underway. A high-end computing cluster "Vikram-100" and a quantum optics laboratory are now operational at PRL.



## ISRO's Space Science Promotion Scheme: ISRO-SSPS

The basic aim of this scheme is to strengthen the research activities in Space Science in Universities. ISRO-SSPS is to meet the demand / requirement of high quality human resources for the growth of space science activities and to address the issue of attracting more faculty and students' participation in space science research at national level. Seven Universities are being supported under the phase-II activities of this scheme.

Funding support consists of the recurring grant for a period of five years which includes the M.Sc / M.Tech fellowship to meritorious students and honorarium and travel support to guest faculty.

## Astronomy Olympiad

Indian Astronomy Olympiad Programme (IAOP) is intended to encourage students with good foundations in Physics and Mathematics and an interest in Astronomy to pursue further studies in this field. Homi Bhabha Centre for Science Education (HBCSE) is coordinating this activity with the support of ISRO / DOS. This year the International Olympiad in Astronomy and Astrophysics was hosted by India and held at NISER, Bhubaneswar during December 09-19, 2016.

## Nineteenth National Space Science Symposium – (NSSS-2016)

The nineteenth National Space Science Symposium (NSSS-2016) was held at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram, during February 09-12, 2016. NSSS sponsored by ISRO is being conducted once in two years with a view to promote the Space Science activity in the country and inspire more and more young talented individuals to consider this as a career option.

Prof. U. R. Rao, Chairman PRL council and ADCOS-ISRO, inaugurated through a video message addressing the delegates and wishing the symposium a grand success. The Guest of Honour, Dr. M. Rajeevan, Secretary MoES, Govt. of India, stressed on the need to have a close collaboration between ISRO and MoES, especially in the area of the remote sensing of the earth's atmosphere using satellites to tackle important scientific problems of present times.

The NSSS-2016 has the distinction of having the maximum number of delegates so far. Overall, in NSSS-2016 about 250 oral presentations and 550 poster presentations were made with representation from almost all states in the country. In line with ISRO's endeavors that always encouraged young scientists, 60% of the contributed papers presented in the oral sessions were by researchers and scientists below 35 years of age and 27 best paper awards were given, again the highest so far.



# Sponsored Research

## Introduction

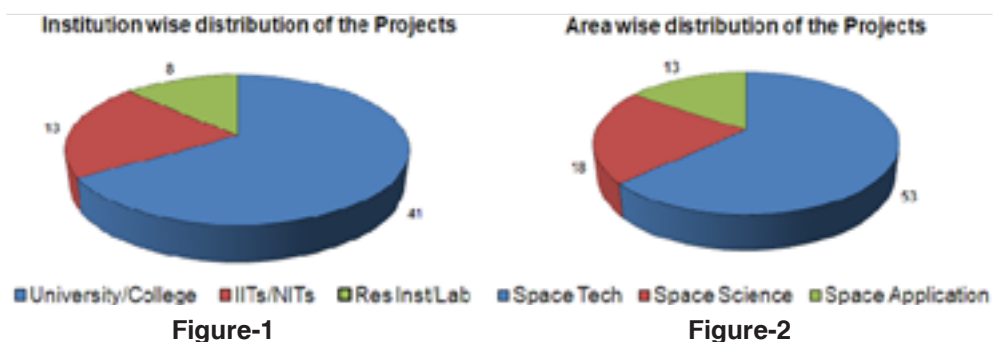
RESPOND (Research Sponsored) programme started in the 1970s aims at encouraging academia to participate and contribute to various space related activities. Under RESPOND, projects are taken up by universities / academic institutions in the areas of relevance to the Indian Space Programme. Apart from this, ISRO has also set up Space Technology Cells (STC) at premier institutions like Indian Institute of Technologies (IITs) at Bombay, Kanpur, Kharagpur and Madras, Indian Institute of Science (IISc), Bengaluru and Joint Research Programme with Savitribai Phule Pune University (SPPU) to carry out research activities in the areas of space technology and applications.

The main objective of the RESPOND Programme is to establish strong links with academic institutions in the country to carry out research and developmental projects which are of relevance to space programmes. The major activity under RESPOND is to provide support to research projects in a wide range of topics in space technology, space science and space applications areas to universities / institutions. In addition, conferences, workshops and publications, which are of relevance to space programme, are also being supported.

## Activities

During 2015-2016, RESPOND supported 50 New Projects and 34 Ongoing Projects and five Space Technology Cells and Joint Research Programme with Savitribai Phule Pune University. In addition, ISRO Chairs and 110 conferences / symposia / publication and other scientific / promotional activities were supported. During the year, 36 projects sponsored earlier were successfully completed. Scientific publications emerged out of these projects apart from fulfilling the objectives. Principal Investigators (PI), Co-PIs and research fellows involved in various projects had interacted with various ISRO focal points / experts in realising the projects.

During the year, RESPOND has supported 41 Universities / Colleges, 13 IITs / NITs and 8 Research Institutes / Laboratories to take up Projects, both new and ongoing (Figure-1). Further, during the year, a large number of projects have been supported in the area of Space Technology (53) followed by Space Science (18) and Space Applications (13) (Figure-2).



**Projects at Space Technology Cells:** During the year, RESPOND has supported 70 new projects and 127 ongoing projects of five Space Technology Cells and Joint Research Programme at Savitribai Phule Pune University and further 57 projects have been completed. Details are given in the table below:

Sl. No.	Name of STC / JRP	Number of Projects		
		New	Ongoing	Completed
1.	IISc Bengaluru	19	30	16
2.	IIT Madras	11	16	6
3.	IIT Bombay	10	10	10
4.	IIT Kanpur	12	23	6
5.	IIT Kharagpur	10	32	16
6	SP Pune University	8	16	3
<b>Total</b>		<b>70</b>	<b>127</b>	<b>57</b>

The projects are reviewed by domain experts in ISRO and later by Joint Policy Committees consisting of experts from ISRO and the academia. In addition to the R&D Projects, ISRO under RESPOND programme has established research chairs at Indian Institute of Science (IISc) Bengaluru, National Institute of Advanced Studies (NIAS) Bengaluru, IIT Kharagpur, SP Pune University and Bangalore University.

### Highlights of Some of the RESPOND Projects

- **Whole Field Strain Measurement using Digital Reflection Photo elasticity:** Different parts of launch vehicle structures undergo different stress / strain. This project brought out a novel and accurate method for their measurement. Under this project, Strain measurement software algorithm has been developed and demonstrated.
- **Nanomechanical Characterisation of Carbon Carbon Composites:** The project aimed at developing and characterising the Vanadium oxide based variable emittance coatings that change effective emittance with respect to temperature and is useful for the thermal control of spacecraft that experiences variable thermal fluxes in-orbit. Under this project, the methodology to evaluate the Young's modulus and the nano-hardness required for Carbon-Carbon (C-C) composite materials in the focused area of fibre, matrix and fibre-matrix interface was developed.



- ***Development of dispersion process of high solid containing propellant slurry with nano Aluminium particles:*** Under this project, an alternative sonochemical procedure for production of Aluminium nanoparticles from Aluminium isopropoxide and Lithium aluminum hydride and its homogeneous dispersion in DOA (Dioctyl Adipate) and HTPB (Hydroxyl Terminated Poly Butadiene) has been developed. Methodology of production of nano Aluminium particles by sonochemical process and its dispersion in DOA and HTPB by sonication and using Hydrodynamic cavitation set up was developed.
- ***Condition monitoring and health assessment for bearings of cryogenic engine turbo pump:*** Under this project, a unified software was developed for processing and analysis of the vibration data and for quick and easy viewing and interpretation. The software is useful to monitor both bearing and rotor vibration signals. Through the result, it is possible to identify bearing defect and its severity level and thus achieving effective condition monitoring and health assessment of the turbopump bearings.
- ***Surface measurements of atmospheric radioactivity and its influence on electrical conductivity of earth's atmosphere:*** Under this project, the atmospheric radioactivity, electric field, air-earth current and aerosols near the earth's surface were experimentally studied. These were then used for model studies of the lower atmosphere, variation of radioactivity, ionisation, aerosols and electrical conductivity were also studied. The scientific problems like effect of aerosols on conductivity, development of ion-aerosols model for prediction of conductivity were addressed.
- ***Design of active flexible and re-configurable parabolic antenna using SMA based smart actuators:*** Under this project, a new strategy of shape control of a flexible parabolic antenna actuated with Shape Memory Alloy (SMA) springs has been developed. Such antenna systems can be used to send signal at a desired location by a controlled deflection of the antenna system. To verify the findings, a controlled closed loop algorithm has been developed using MATLAB / SIMULINK in the d-space environment for a one meter diameter Antenna System.
- ***Effect of geometrical and flow parameters on drop size distributions for sprays from gas-centered swirl coaxial atomizers:*** Under this project, characteristics of sprays discharging from the research and industrial atomizer configurations were studied. Experimental results were obtained on the effect of flow conditions on the drop size characteristics of sprays discharging from the gas-centered swirl coaxial atomizers. The results obtained on the analysis were compared for the two different gas-centered swirl coaxial atomizers. The results of the project were used for the indigenous development of swirl injectors for main thrust chamber of semi-cryogenic and tri-propellant engines. The injector parameters of oxidiser rich staged combustion cycle engines can be chosen based on the available experimental results.



- **Signal Processing for Performance Improvement of Multi-Object Tracking Radar (MOTR):** The goal of this project is to find the best signal processing algorithms which can be used for tracking objects in the Multi-Object Tracking Radar (MOTR) at SDSC, SHAR. The project has successfully delivered Python, C and VHDL Codes of Cell Averaging Constant False Alarm Rate (CA-CFAR), Ordered Statistics CFAR (OS-CFAR) and Trimmed Mean CFAR (TM-CFAR). Real time multiple object tracking of PSLV-C34 was done on June 22, 2016 using CFAR algorithm code developed under the project.
- **Dual Band Dual Polarised Multi-layered Broadband Microstrip Antenna Array for Satellite Communication:** Under this project, a dual band dual polarised multilayer broadband microstrip antenna at S and X-bands using two configurations was designed. Such an antenna will be useful in replacing the requirements of two different antennas with a single antenna resulting in space saving. Antenna fabrication and testing have been done.



## Indian Space Industry

Towards meeting the demands of national needs of space systems and services in various application areas, the Indian space programme has been supported by valuable contributions from Indian industry. Participation of industry in the realisation of space systems such as spacecraft, launch vehicles, and establishment and operations of ground support systems and facilities and implementation of application programmes for the benefit of end users have been steadily growing.

As a sequel to the National Meet on promoting space technology based tools and applications in Governance and Development, the demands for potential applications of space systems and services in various new areas are on the increase. This scenario warrants higher order of participation of Indian industry in realisation of space systems in short turn-around time. With the matching enthusiasm from Industry, ISRO Centres and Units have been geared up to make use of the emerging opportunities. Development of Space Industry would not only support meeting the national demands but also catalyse the entry of Indian Industry entering international space commerce.

### Technology Transfer

Technology Transfer is act of policy pursued by the Department of Space for over four decades through which the technologically advantageous results of in-house R&D in space activities performed by work centres of ISRO, are transferred to industry for turning over to various applications. Modes of Technology Transfer include – ‘Spin-Off’ for non-space applications, ‘Buy-Back / Productionisation’ for the continued requirements for space activities and ‘Space Applications’ for taking the benefits of space technologies to society.

During the year, 13 technology transfers have been made to Indian industries in the areas of materials, chemical, adhesives, pressure transducers, earth station antenna, etc. These are: Ku/DBS-Band Feed System for Earth Station Antennas, Epoxy Film Adhesive, EFA 4330, Thermal Protection System, SSF P70, Silica Fibre, Silica Granules, Nickel Hydrazine Nitrate (NHN), Phenolic Resins PF 106 & PF 108, RTV Silicone adhesive SILCEM R9, Polydimethylsilane (PDMS), Thermal sensors and Pressure transducers for spacecraft applications.

Another technology, FEAST Software, a Finite element based structural elements analysis software is being used increasingly by the R&D institutions and Universities across the country. To accelerate the usage of FEAST among technical community, marketing licenses were awarded two more agencies during the year.

Seven more technology transfers are in the pipeline. Through an established mechanism, new technology transfers are being identified from the R&D activities of work Centres of ISRO regularly and pursued for transfer through a professional manner.



## Productionisation through Industry

Increased requirements of standardised subsystems for spacecraft are realised through qualified vendors regularly. Such items include –

- Electronic subsystems, dual channel Telemetry receivers, Bit Synchronizers, QPSK Demodulators, electronic packages for remote sensing satellites, DC-DC Converters, RF packages, Hybrid Micro Circuits, Surface Mounted Devices, multi layer printed circuit boards.
- Mechanical items and components with surface finishing for thermal treatments through Electroplating processes and bonded film dry lubrication for mechanism components.
- Thermal control element components, both active and passive such as Heat Pipes, Thermo-foil Heaters, and Optical Solar Reflectors, for which technologies were transferred to industry;
- Equipment for ground test systems such as solar array simulator, battery simulator, power control units, active sink modules, data acquisition systems for sub-systems and payloads.
- Checkout Software for remote sensing payloads and meteorological payloads.
- Fabrication of Li-ion Batteries and Solar panels for spacecraft power generation are realised through BHEL on productionisation mode through contracts. Further, the existing contract is planned to be revised for augmentation of facilities to increase throughputs.
- Production and supply of PS2 & PS4 propellant tanks and Integrated L40 liquid stages for PSLVs are continued with Aerospace Division of HAL.
- Production of Vikas engines, PS4 / RCT engines, PS4 RCS thrusters, propellant tanks, water tanks and stage interface elements continued through industry to meet launch vehicle programmatic targets.
- A dedicated facility for cleaning Titanium gas bottles has been established at M/s Brahmos Aerospace, Trivandrum, towards reducing the integration time for PS2 / GS2 / PS4 / L110 stages
- Production of Electrical actuators and DC Geared motor, Production of satellite thruster parts, propellant tanks and satellite components parts are realised through various industries.
- Transducer production and integrated production of 21NA and DPT continued through industries. The first batch of Differential Pressure Transducers (DPT-84) was realised under technology transfer.
- Production of pressure vessel parts for spacecraft propellant tanks, spacecraft propulsion components and temperature sensors, MEMS & IDLV Pressure transducers was continued through industry.



## **A special initiative on Spacecraft Assembly Integration and Test support from Industry**

- To cope with the increased number of spacecraft of the order of 10 to 12 per year, to meet the national demands in the areas of Communication, Remote Sensing and Navigation, a need has been felt that standard spacecraft systems could be realised through Indian Industry on production mode, after qualifying the Industry to take up manufacturing of electronic and mechanical subsystems and fabrication at subsystem levels and test support. To get engaged in system level activities, the Industry needs to get exposed, trained and qualified with spacecraft level Assembly, Integration and Test activities. Besides, it warrants establishment of high cost vis-à-vis high technology facilities to realise systems for space applications.
- In this regard, an initiative was taken up to identify a suitable vendor who could be trained and qualified for handling spacecraft level activities. After due process of interest exploration, technical interactions, floating of Request For Proposal, technical valuations, short listing of vendors, and call for tenders, an industry partner, who is competent on techno-commercial aspects, has been identified to provide technical manpower to ISRO in the first phase. Expert manpower from this industry partner will be actively involved in integrating two satellites using the infrastructure provided by ISRO.
- A contract has been signed recently with a private industry who leads a consortium of a few other industries. This is the first time an Indian Private Industry will be partnering ISAC in integrating satellites. Under this hand-holding arrangement, identified team of vendor would be trained and qualified by ISRO. All the hardware for the sub systems of spacecraft, spare infrastructure for assembly, integration and testing of two repeat types of navigation satellites will be provided by ISRO.

## **Technology Utilisation**

- During the period under the expansion and distribution of IRNSS ground receivers, 16 MoUs were signed with different academic and research institutes across the country for Field Trial and Data Collection of the receiver.
- Besides, a novel MoU was signed with Directorate of Employment & Training, Labour and Employment Department, Govt. of Gujarat. Under this MoU, 30 students from ITI were trained for skill development for one month in SAC campus.
- A MoU was signed with Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India for collaboration in the area of utilisation of SAR data for vegetation characterisation and retrieval of above ground biomass of Indian forests.



### Intellectual Property Rights (IPR)

- During the year, the tally of ISRO's IPR assets were added with 15 patent grants. Further, 12 more patent applications were filed on new inventions.
- During this period, Space Applications Centre (SAC), Ahmedabad has become first centre of ISRO and second in the country to register a Design Layout for a 50-60 GHz Sub-harmonic IQ Mixer under Semiconductor Integrated Circuits Layout Design Act, 2000.



## Space Commerce

Antrix Corporation Limited (ACL), a wholly owned Government of India Company under Department of Space, has undertaken a number of initiatives for global marketing of space products and services emanating from the Indian space program. There has been a steady increase in the revenues and customer base of the company.

The transponder provisioning services have registered a significant growth in business operations with increased capacity being provided during the year for diverse applications. Currently, a large number of transponders from INSAT / GSAT fleet are provisioned to Indian users for Television Broadcasting (TV), Direct-to-Home (DTH), Digital Satellite News Gathering (DSNG), Very Small Aperture Terminal (VSAT) and Telephony services. The services realised in the process address a wide range of social and business needs. Additional transponders were provisioned for meeting the ever-increasing requirement of customers. The rapidly growing demand from VSAT services from Government and public sector enterprises, along with pan India digitisation efforts in the context of DTH, is expected to fuel the demand for satellite communication capacity in the country. Antrix is geared to meet these requirements in a timely manner.

Antrix was able to establish PSLV as a reliable satellite launcher and could consolidate the launcher as a major player in the small satellite launch business. Till date, PSLV has launched 79 international customer satellites from 21 countries. During this year, ANTRIX was able to enter into contract with major small satellite companies like Planet Labs, Terra Bella, etc., and launched 12 nano satellites and 3 mini satellites, as co-passengers in PSLV-C34.

In addition, in the PSLV-C35 mission, five international co-passenger satellites- ALSAT-1B, ALSAT-2B, ALSAT-1N, Pathfinder-1 and NLS-19-were launched. ALSAT-1B is an Algerian earth observation satellite for monitoring agriculture, disasters and environment. ALSAT-2B is a high-resolution remote sensing satellite with panchromatic and multispectral imaging capability. Pathfinder-1 is a commercial high resolution imaging microsatellite from the USA. ALSAT-1N and NLS-19 were nano satellites from Algeria and Canada, respectively.

The outlook for launch services is promising with numerous agreements in hand for launching international customer satellites. During the year, launch service agreements were signed for dedicated PSLV for a customer and several international customer satellites as co-passengers.

The global marketing of IRS data is being pursued in collaboration with its international partners. Currently, Antrix markets IRS data and services from RISAT-1, Resourcesat-2, Cartosat-1 and Oceansat-2 satellites. One of the major accomplishments has been the operationalisation of International Ground Stations (IGS) for customers from Germany and Scotland for reception of OCM data from Oceansat-2 satellite. The operational IRS Ground Stations (IGS) are at Norway for RISAT-1, Germany, Iran and Algeria for Cartosat-1 and Germany for Resourcesat-2, Germany and Scotland for Oceansat-2 satellites. Antrix is in the process of expanding the IRS ground segment market outreach with plans for setting up of more stations outside India.



In the area of the export of satellite subsystems and systems, enquiries from prospective customers are being pursued. The initiatives undertaken over the past year are now yielding results. Sun Sensors for an Indian customer is ready for delivery and modalities are being worked out for the supply of other systems like Solar Arrays, etc.

In the mission support services area, there has been a good progress in the provision of Telemetry and Telecommand (TTC) support to international customers. Today, Antrix is recognised as one of the most prominent service providers from this part of world. Antrix's capabilities in providing TTC support are well established, with prominent international customers using its network of ground stations for meeting various mission requirements. As part of the long term framework agreement with an international customer, Antrix supported the Ka-band and Ku-band Transfer Orbit Support Service (TOSS) mission of international satellites from MCF, Hassan. Launch support for a satellite of space agency from France was provided from ISTRAC, Lucknow. In addition, Antrix is supporting the critical orbital relocation exercise of an international satellite for a prestigious customer from Europe. New business opportunities are being explored with international customers.

Antrix Corporation Limited and ISRO in coordination with Confederation of Indian Industry (CII) organised the fifth edition of 'Bengaluru Space Expo (BSX) 2016' and a concurrent conference 'World Space Biz 2016' during September 01-03 at 'Bengaluru International Exhibition Centre (BIEC), Bengaluru. The event had the participation of a large number of delegates of industry from India and abroad, ISRO and foreign space agencies. There were seven interesting technical sessions during the conference and in addition, there were highlight address and lightning talks on futuristic communication by eminent industry professionals. More than 70 Indian and international exhibitors had their stalls at BSX 2016. A large number of visitors from industry and academia apart from general public visited the exhibition. Two new initiatives - B2B meeting on Small Satellites Development and Solar Panels and Satcom Services User Consultations - were organised during BSX 2016. The trade exhibition conducted alongside the expo saw participation by various space industries from India and abroad as well as space agencies. Overall, the Expo conveyed the Technology scenarios, challenges and opportunities in Space Business and was well received by the participants.



**BSX 2016 Conference Inauguration**





**Exhibitors at BSX 2016**

The Committee On Papers Laid On the Table (COPLAT), Rajya Sabha reviewed Antrix activities during their visit to Bengaluru. Industry delegations and high level officials from leading global space companies visited Antrix to discuss commercial projects of mutual interest.

As part of its Corporate Social Responsibility (CSR) efforts, Antrix has undertaken activities related to the re-habilitation of physically challenged (orthopedically, visually and hearing impaired) personnel in Sulurpeta, Tada and Doravari Satram Mandals, Nellore District, Andhra Pradesh, in association with Artificial Limbs Manufacturing Corporation of India (ALIMCO), a PSU under Government of India, Ministry of Social Justice and Empowerment. Antrix has completed building sanitation facility in 33 Government Schools located in Chikkaballapur District, Karnataka, utilising the services of M/s. Sulabh International and with the involvement of District authorities, Government of Karnataka. The construction of community sanitation facility in Government hospitals in Chikkaballapur and Bengaluru is in progress.

Antrix has adopted Brahmasandra Village, Sira Taluk, Tumkur district for integrated and holistic development towards making it a model village. In addition, setting up of a sewerage treatment plant at Bhalki, Bidar and construction of two overhead tanks for supplying drinking water to villages at Kadapatra Panchayat, Nellore is progressing well.

Antrix has been conferred “Outstanding CSR Project Award” by Delhi Management Association (DMA) and Indian Institute of Corporate Affairs.



## Systems Reliability and Safety

Directorate of Systems Reliability and Quality (DSRQ) as a nodal agency from ISRO Headquarters continued its effort in extending technical advice and other necessary supports to various ISRO / DOS centres towards ensuring reliability of space systems.

### ISRO Standards

'ISRO Reliability standard-ISRO PAS 503' covering the general requirements for Pyro systems for both launch vehicle and satellites has been prepared. Another important standard on the rain-proofing of Launch Vehicle systems is in advanced stages of realisation by a dedicated team.

ISRO has embarked on a mission to completely indigenise the various Technical standards being adopted at ISRO Centres and Units under the umbrella of ISRO Technical standards. The information regarding the standards in vogue at various work centres was collected and consolidated in the form of a document and a Compendium of 1047 standards has been made. It is also proposed to realise these standards with the involvement of present / former ISRO scientists / engineers, Indian academia, professional bodies and other national stakeholders and a mechanism has also been proposed towards this.

### Sharing of best practices

The ISRO level think-tank Integrated Product Assurance Board (IPAB) continues to play a crucial role in addressing systemic issues and sharing of best practices across ISRO centres.

An exclusive IPAB meeting was organised to address the quality issues at 11 external workcentres of ISRO and the resident production and quality managers of these workcentres actively participated in the deliberations. Dedicated IPAB meetings were also conducted for reviewing ISRO missions like Reusable Launch Vehicle-Technology Demonstrator (RLV-TD), Cartosat-2 Series Satellite, INSAT 3DR and SCATSAT-1.

In pursuit of ensuring uniform quality practices at newer centres of ISRO, specific meetings were held at Semi-Conductor Laboratory, Chandigarh and National Remote Sensing Centre (NRSC), Hyderabad.



## Path-Sampada

Capturing and securing institutional memory has been a challenge for all space faring nations. With a conscious policy of uniformly and accurately documenting the important lessons learned in the realisation of space systems, an ISRO level, intranet based, software platform - 'Path Sampada' has been created by DSRQ with the help of an inter-centre team.

Orientation sessions regarding this software were organised at six ISRO centres and this umbrella is being expanded gradually. This database is expected to serve as a significant tool in the process of sharing important technical knowhow not just from one ISRO centre to other but also from one generation to another. This is all the more essential in the current era of enhanced launch frequencies. It is heartening to note that more than 600 lessons have already been populated into this database till date.

## Continual Improvement

In our endeavor to achieve zero defects in the delivery of space systems, it is essential to strive for continual improvement. Addressing of even the minor anomalies that are sometimes observed in the in-orbit life of spacecraft is considered as an important task towards achieving zero-defects. A detailed mechanism for addressing these anomalies including the root-cause analysis and the related failure analysis has been proposed.

An audit of the contamination control practices at the Semi-Conductor Laboratory, Chandigarh was carried out by a sub-committee and specific recommendations towards further improvement have been made.

ISRO has achieved several successes and has evolved into a respectable organisation in the international arena. ISRO's ties with other international space agencies have also been growing. Imbibing best practices from other international space agencies has also been identified as a significant way of achieving continual improvement. A team of seven Quality and reliability professionals working in the area of spacecraft systems was sent to NASA and the team has come back with excellent suggestions for improvement. Similar effort is also being made in the area of Launch Vehicle systems and a team is being sent to the French National Space Agency (CNES) too in the near future.

## Quality Outreach

A two day workshop on 'Lessons learned from ISRO Space Systems' was organised at ISRO HQ. Close to 130 young scientists and engineers from various centres and units of ISRO participated in this workshop and benefited by the experiences shared by various experts in different aspects of space technology.

Efforts are also on at various ISRO centres for continuing the zero-defect delivery programme which is primarily targeted towards nurturing and sustaining a culture of zero-defects in the delivery of space systems.



## Academia Involvement

- ISRO has had a rich lineage of interaction with academia and attempts are being made to scale this up further. Theoretical modeling and analysis of space systems has been identified as a key area for engaging academia in a gainful manner. Special meetings were organised between ISRO experts and the Indian Institute of Science, Bengaluru and the Indian Institute of Space Science and Technology (IIST), Valiamala, Trivandrum.

## Safety Services

The space programme continued to be free from any major incident during this year. The scheduled launches of PSLV-C33 / IRNSS-1G, PSLV-C34 / Cartosat-2 Series Satellite, PSLV-C35 / SCATSAT-1 and GSLV-F05 / INSAT-3DR missions were successfully completed without any safety related non-conformance. Like previous launches, well established safety procedures, safety standards and emergency preparedness plan were implemented to prevent unforeseen incidence. Safety surveillances were available round the clock during the launch campaign activities. Activities involving production and transportation of solid propellants, earth storable propellants, cryogenic propellants, rocket motors and pyrotechnic materials, etc., and assembly and integration of rocket stages and satellites and high pressure gas servicing at launch pad were carried out under the full time participation of safety team.

The significant achievements of this year are the flight testing of Resuable Launch Vehicle Technology Demonstrator (RLV-TD) and of two Scramjet engines at Mach 5 in Advanced Technology Vehicle (ATV-D02) mission and the readiness of largest liquid stage of ISRO the L110 stage for GSLV-MK III D1 flight. All these milestones were achieved without any safety implications. The other major safety activities like flight acceptance test of steering engines, testing of various subsystems of GSLV-MK III, that is, cryogenic proof pressure testing of helium gas bottles and hot test of fuel booster unit, were conducted under meticulous safety supervision.

Safety surveillance was in place during the fabrication, integration, thermovac test, vibration tests and pressure hold test of GSAT-18, INSAT-3DR, IRNSS-1G and 1F, SCATSAT-1, GSAT 17 & 19 and Cartosat-2 Series Satellites and safety clearance was issued for pressure hold test and dynamic tests of IRNSS 1G & 1F and CARTOSAT satellites. Safety review of radiation sources for various spacecraft was also completed without any waivers.

Safety committees at various ISRO / DOS centres reviewed and cleared locations for construction and commissioning of new facilities. Imparted safety inductions to all personnel joining ISRO and specific safety awareness were given on work related hazards. Training was provided on fire fighting and general safety to all employees of ISRO. Safety promotional activities have been continued through the celebration of National safety day, Fire service day and World environment day by issuing posters and conducting safety seminars.



## Human Resources

The total approved sanctioned strength of the Department as on 01.03.2016 is 16,902, out of which 12,300 are in Scientific and Technical (S&T) category and 4,602 is under administrative category. Proposals for phased augmentation of human resources for DOS / ISRO Centres / Units, in tune with the programmatic targets laid down is under process.

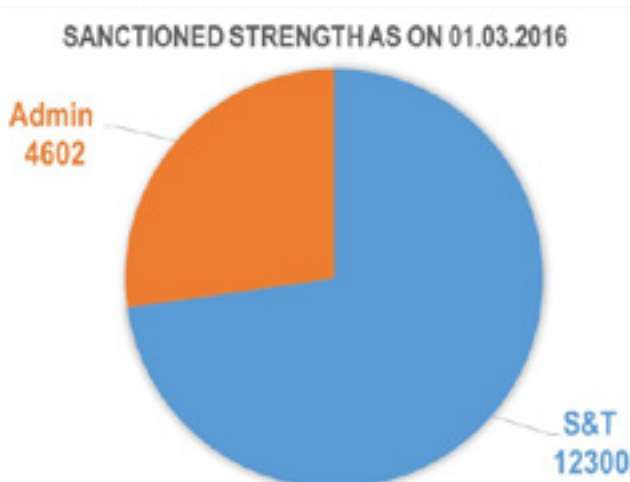
The existing welfare measures such as housing, medical, canteen, schooling for children, etc. are extended to the employees of ISRO under various approved institutional schemes. Life insurance coverage from accidents in the work place is provided to the employees by schemes such as VISWAS and SAFE, a special scheme for assistance to families in exigency, at a relatively low premium through internal trusts.

Key importance is laid to the competency requirements of the individuals, required for contributing effectively and efficiently towards realisation of the organisational goals and resulting achievements. Hence stringent recruitment process is adopted to ensure quality personnel are inducted into the system and greater importance is attached towards continuous development of the human resources, periodically in tune with the programmatic requirements.

Centralised recruitment of Scientist / Engineers with degree in engineering and is continued during the year. Online applications are invited through ISRO website and selections / inductions are completed through the process of written test and interview on an all India basis. Also Centralised recruitment process is continued for recruitment of Officers in Administrative area, Office Assistants and Junior Personal Assistants during the year. Further, specialised recruitments, based on the Centre's requirements, are made by respective Centres / Units.

In order to induct quality manpower into the systems, the campus recruitments at IITs (fifteen campuses) has been revived and selections are under process.

ISRO / DOS has been absorbing bright graduates from the Indian Institute of Space Science and Technology (IIST) on successful completion of the B.Tech programme, meeting the benchmark set. The sixth batch of students, who were admitted to B.Tech during September 2012 at IIST have graduated during June 2016. A total of 96 eligible students are inducted in all DOS / ISRO Centres / Units.



## TRAINING

Training and Development activities are envisaged through both, Centralised and Decentralised systems. The scheme of Centralised Induction Training Programme for newly joined Scientist / Engineers, introduced during 2002, is being continued. The training programme is aimed at introducing the newly recruited engineers to the ISRO systems by providing necessary exposure to the ISRO programmes, achievements, rules, regulations, systems, processes, etc. Similar Centralised Induction Training programmes are being given to Office Assistants and Junior Personal Assistants in Administrative areas, conducted by different Centres / Units on a rotational basis.

All the officers in Purchase and Stores area have been sponsored for specialised training programme at National Institute of Financial Management, Faridabad for programme on Public Procurement Policies.

Customised, exclusive management development training programmes for middle level S&T personnel are organised at Administrative Staff College of India (ASCI), in three batches of size 20 each.

Annual calendar is drawn for organising Centralised Structured Training Programmes (STPs) to deal with the training on core technical subjects. Middle level engineers from various Centres engaged in relevant activities are trained through these STPs organised by the different Centres, as per the annual STP calendar.

Space Studies Programme (SSP) 2016 for young scientists / engineers organised by International Space University at Israel during June-August, 2016 was continued during the year and 6 Scientists / Engineers from different Centres / Units attended the programme.

As a part of executive training, 5 senior Project Directors / Associate Project Directors were trained at Indian Institute of Management, Ahmedabad (IIM-A) on Project Management subjects.

Based on the functional and specialised requirements, decentralised training programmes are administered at respective Centres / Units of DOS / ISRO at various intervals.

### I APPRENTICE TRAINING

Under the Apprentices Act, 1961, training has been imparted to 3,483 apprentices in Centres / Units of the Department in the Technical and Commercial Trades.

### II RESERVATION IN SERVICES

#### a) SCHEDULED CASTE AND SCHEDULED TRIBES

The Department has been observing the guidelines for recruitment, promotion and the welfare of Scheduled Castes and Scheduled Tribes, Table-I indicates the status of representation of persons belonging to Scheduled Castes and Scheduled Tribes.



**b) PERSONS WITH DISABILITIES**

Position regarding appointed Persons with Disabilities is given in Table - II

**c) EX-SERVICEMEN**

The status of representation of Ex-servicemen is given in Table – III.

**d) OTHER BACKWARD CLASSES (OBCs)**

3,742 persons belonging to Other Backward Classes are existing at present. Out of the 3,742 OBCs, 226 were appointed during the year.

**III) WOMEN EMPLOYEES**

There are 1890 Women Employees in the Scientific and Technical categories and 1262 Women Employees in Administrative categories in the Department as per details in Table-IV. They represent 20% of personnel in the Department.

**IV) JOINT CONSULTATIVE MACHINERY (JCM)**

The scheme of Joint Consultative Machinery (JCM) of the Department continued to function satisfactorily.

**V) CONFERENCES AND WORKSHOPS**

**a) National Conference for ISRO Women Employees**

National Conference for ISRO Women Employees was organised at Vikram Sarabhai Space Centre (VSSC) at Thiruvananthapuram on March 09, 2016. Women employees from various DOS / ISRO establishments participated in the Conference as delegates and presented papers.

**b) International Day of Yoga**

The United Nations has declared June 21 as the 'International Day of Yoga' on the topic of 'Yoga for Harmony and Peace'. As part of the celebrations, a mass yoga practice / demonstration was organised in DOS / ISRO establishments.

**c) Dr. B. R. Ambedkar's Birth Anniversary Celebrations**

125th Birth Anniversary of Bharat Ratna Dr. Bhimrao Ramji Ambedkar was celebrated in DOS / ISRO establishments in 2016.



TABLE - I STATUS OF SCHEDULED CASTE / SCHEDULED TRIBE PERSONNEL

Sl.No	Centre / Unit	Total Strength of Employees 2016-17	Strength of SC Employees 2016-2017	Strength of ST Employees 2016 -2017
1	DOS / ISRO HQ	406	61	23
2	VSSC	4494	357	69
3	ISAC	2439	294	94
4	SDSC-SHAR	2002	313	129
5	SAC & DECU	1791	189	125
6	LPSC	1213	138	28
7	NRSC	853	106	33
8	ISTRAC	433	69	17
9	MCF	331	40	16
10	ADRIN	169	21	5
11	IIRS	118	14	6
12	PRL	221	8	1
13	SCL	585	108	6
14	NARL	64	9	1
15	NESAC	32	2	4
16	IIST	92	3	0
17	IPRC	638	134	11
<b>TOTAL</b>		<b>15881</b>	<b>1866</b>	<b>568</b>



TABLE - II STATUS OF PERSONS WITH DISABILITIES

Sl. No	Centre / Unit	Total Strength of Employees 2016-2017	Strength of Persons with Disabilities	Classification of Employees with Disabilities			
				Deaf & Dumb	Blind	Partially Blind	Orthopedically Handicapped
1	DOS / ISRO HQ	406	7	0	0	1	6
2	VSSC	4494	106	21	2	17	66
3	ISAC	2439	60	13	6	2	39
4	SDSC-SHAR	2002	59	4	1	0	54
5	SAC & DECU	1791	38	4	2	0	32
6	LPSC	1213	26	5	0	0	21
7	NRSC	853	19	2	0	0	17
8	ISTRAC	433	11	1	0	0	10
9	MCF	331	4	1	0	0	3
10	ADRIN	169	3	0	0	0	3
11	IIRS	118	4	0	1	0	3
12	PRL	221	4	1	0	0	3
13	SCL	585	3	0	0	0	3
14	NARL	64	1	0	0	0	1
15	NESAC	32	0	0	0	0	0
16	IIST	92	1	0	0	0	1
17	IPRC	638	12	0	0	0	12
<b>TOTAL</b>		<b>15881</b>	<b>358</b>	<b>52</b>	<b>12</b>	<b>20</b>	<b>274</b>



TABLE - III STATUS OF REPRESENTATION OF EX-SERVICEMEN

Sl. No	Centre / Unit	Total Number of Employees in Group - C 2016-2017	Total Number of Ex-Servicemen in Group - C 2016-2017
1	DOS / ISRO HQ	88	8
2	VSSC	907	106
3	ISAC	363	20
4	SDSC-SHAR	612	17
5	SAC & DECU	251	4
6	LPSC	195	37
7	NRSC	87	0
8	ISTRAC	44	4
9	MCF	53	2
10	ADRIN	33	3
11	IIRS	18	0
12	PRL	23	0
13	SCL	59	0
14	NARL	5	0
15	NESAC	0	0
16	IIST	5	0
17	IPRC	113	18
<b>TOTAL</b>		<b>2856</b>	<b>219</b>



TABLE - IV WOMEN EMPLOYEES

Sl. No	Centre / Unit	Total Number of Employees 2016-2017	Number of Women Employees 2016-2017	
			Scientific & Technical Staff	Administrative Staff
1	DOS / ISRO HQ	406	23	115
2	VSSC	4494	517	463
3	ISAC	2439	515	140
4	SDSC-SHAR	2002	125	133
5	SAC & DECU	1791	226	88
6	LPSC	1213	78	107
7	NRSC	853	143	60
8	ISTRAC	433	72	36
9	MCF	331	30	11
10	ADRIN	169	29	11
11	IIRS	118	18	8
12	PRL	221	10	18
13	SCL	585	35	16
14	NARL	64	5	8
15	NESAC	32	7	2
16	IIST	92	18	6
17	IPRC	638	39	40
<b>TOTAL</b>		<b>15881</b>	<b>1890</b>	<b>1262</b>



## Vigilance

Vigilance Awareness Week was observed commencing with administering of pledge to the employees on October 31, 2016 to November 05, 2016. The theme of observing the Vigilance Awareness Week for this year was "Public participation in promoting Integrity and eradicating Corruption".

The activities carried out during Vigilance Awareness Week-2016 in all the Centres / Units of ISRO are:

Centre	Activity
VSSC	- Conducted Elocution competition. - Arranged a Lecture by eminent personality.
LPSC	- Arranged a Lecture by eminent personality. - Inaugurated in-house intranet Web Portal on CCS (Conduct) Rules.
ISRO Hqs	- Conducted Elocution competition. - A Skit Programme performed on anti-corruption activities.
NRSC	- Conducted Essay writing, Elocution, Quiz competitions. - Arranged a Lecture by eminent personality.
IPRC	- Conducted an Essay writing competition. - Arranged a Lecture by eminent personality.
NE-SAC	- Conducted Quiz competition. - Arranged a Lecture by eminent personality.
SCL	- Conducted an Essay writing competition. - Arranged a Lecture by CVO.
PRL	- Arranged an Essay writing competition.

The details of Disciplinary (non-vigilance) and vigilance cases dealt are as below:

Category of Employees	Type of cases	Cases pending as on 01.10.2015	Cases received during 01.10.2015 to 30.09.2016	Total (Col. 3+4)	Disposed during 01.10.2015 to 30.09.2016	Pending (Col. 5-6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Group - A & Group-B (Gazetted)	Disciplinary (non-vigilance)	09	01	10	02	08
	Vigilance	08	00	08	00	08
Group - B (non-gazetted) Groups C & D	Disciplinary (non-vigilance)	04	05	09	07	02
	Vigilance	02	00	02	01	01
	<b>Total</b>	<b>23</b>	<b>06</b>	<b>29</b>	<b>10</b>	<b>19</b>



## Progressive use of Hindi

- Implementation of Hindi in the Department of Space (DOS) continued with vigor during the year. The Official Language Implementation Committees (OLICs) both at the Department level and at Centres / Units held its quarterly meetings to review the progress in the use of Hindi. DOS / ISRO and its Centres and Units have also participated in the meetings of Town OLIC constituted in respective Towns.
- The Second meeting of Sanyukt Hindi Salahkar Samiti (JHSS) for DOS and DAE was organised in New Delhi under the Chairmanship of MOS, PMO on November 15, 2016.
- The Second Sub Committee of the Committee of Parliament on Official Language inspects various Centres / Units of the Department regularly. This year the Committee visited DOS Branch Secretariat, New Delhi on July 27, 2016 and Satish Dhawan Space Centre on September 15, 2016 with regard to the progress made in the Implementation of Official Language.
- All the Centre / Units of the Department located in 'A', 'B' and 'C' region have achieved the target fixed for correspondence by the Department of Official Language.
- During the year an amount of ₹4,32,107 has been spent for the purchase of Hindi books for Library, which is in accordance with the target set up by DOL.
- During the year, the Department has spent ₹1,01,03,862 for the publication of advertisement in Hindi in the newspapers.
- In order to implement Hindi in more meaningful and effective manner and to evaluate the progressive use of Hindi in DOS / ISRO Centres / Units, an Annual Inspection Programme was drawn up by Department and inspections were carried out. The Officers from Regional Implementation Offices of Department of Official Language have also inspected the various Centres / Units to review the progressive use of Hindi.
- Internal inspections of various Section of DOS / ISRO and also other Centres / Units were carried out to increase use of Hindi in day-to-day work and the Sections doing best implementation of Official Language were awarded.
- The Hindi Training Programme under the New Hindi Training Course introduced by the Hindi Teaching Scheme of the Government of India, "Parangat", has been introduced in the Department during the year. 20 officers / employees from DOS / ISRO HQ have been trained under this scheme.
- Other training programmes in Hindi through Hindi Teaching Scheme, under Correspondence course and other Departmental arrangements like training through Video Conferencing have been strengthened. The percentage of employees possessing working knowledge of Hindi in all DOS / ISRO Centres / Units has considerably increased to more than 80%. The Centres / Units have been requested to prepare an action plan for imparting training to the remaining employees and to complete the training programme at the earliest. Hindi Stenography training classes were conducted through video conferencing weekly thrice for those who have not yet completed the Hindi Stenography



training. Out of the total strength of 16,902 in the Department, 13,605 have the working knowledge of Hindi and 2,746 are proficient in Hindi and 98 employees are undergoing training.

- During the year, three levels Translation Training of Central Translation Bureau under auspices of Town OLIC organised in Antariksh Bhavan by Central Translation Bureau, Bengaluru for Hindi Translators of ISRO Centres / Units and other central government offices was completed.
- Hindi Day, Hindi Week, Hindi Fortnight / Hindi Month and Hindi Workshops have been organised, in all DOS / ISRO Centres / Units, during which competitions in essay writing, noting and drafting, typing, quiz, poetry writing, story telling, what picture speaks? News Reading, Memory, Elocution, Conversation, etc. have been conducted. These competitions have been organised for Hindi speaking and non-Hindi speaking employees separately. The prizes have also been awarded separately for each category.
- In order to implement the recommendation of the Joint Hindi Salahkar Samithi regarding propagation of Hindi from house-to-house, the family members of the employees were included during Hindi Fortnight celebrations in all Centres / Units of the Department and there was an overwhelming response.
- The children of the employees those secured highest marks in Hindi in class X & XII were awarded.
- With a view to refresh and update the knowledge of Official Language personnel an 'Official Language Orientation Programme' was organised at MCF, Hassan during December 2016.
- Also, a Special Orientation Programme was conducted by DOS / ISRO HQ during July 14-15, 2016 with the topic - "Space Science Glossary" of the Department that had been recently updated and printed.



Glimpses of Special Official Language Orientation Programme held during July 14-15, 2016



- World Hindi Day was celebrated on January 10, 2017 in all Centres / Units of the Department by conducting various programmes.
- Department plays an active role in the activities of Town OLIC. It conducts various programmes under the auspices of Town OLIC. A one day orientation programme for the heads of office of all member offices of Town OLIC was conducted in CPRI. Many officers of the Department took part in this programme. Elocution competition was organised by the Department for the Town OLIC member offices in Hindi on November 09, 2016.
- On the occasion of Vishwa Hindi Diwas on January 10, 2017, a programme on “Role of Town OLIC in increasing the progressive Use of Hindi” was organised for all Central Government offices situated in Bengaluru under the auspices of Town OLIC in Antariksh Bhavan.
- The Incentive Scheme “Vikram Sarabhai Maulik Hindi Lekhan Yojana” introduced to encourage the Scientists of the Department to write books on Scientific subjects in Hindi continued during the year. Eight books in Hindi on Scientific subjects have been written by the Scientists of Space Applications Centre, Ahmedabad and Satish Dhawan Space Centre and ISRO Satellite Centre during the year. All these eight books have been published by the Department. Publication of Technical Articles by the Scientists of the Department in leading magazines continued during the year. About eight articles were sent to Department of Official Language, New Delhi to be considered for award.
- DOS / ISRO HQ in-house magazine “Disha”, compendium of technical articles “Antariksh Gyan Sarita” were published during the year.
- A book on AstroSat written by the Scientist of the Department had been translated in Hindi and released on the occasion of AstroSat completing one year.
- Several brochures, panels (22) and stickers / posters on Indian Space Programme and Booklets on Glimpses of Indian Space Programme, PSLV-C35, IRNSS-1F & 1G, GSLV-D5, LVM3-X / CARE, GSLV-F05, NavIC, GSAT-6, etc, were brought out in Hindi. “Antariksh Bharat” biannual technical magazine was also brought out by Department in Hindi. In-house Hindi magazines were brought out by various Centres / Units of the Department.
- ISRO conducts several outreach programmes also to reach out the space activities to the common man and student community. Exhibition in Hindi on Space were organised in schools during the year.
- The website of the Department has been revamped. Hence the Hindi Website in par with that of English is being updated. In addition to Department’s own Website, SAC, PRL, NRSC and NARL also have their own Websites. ISAC, VSSC, LPSC, SHAR also have internal web pages on intranet in Hindi.
- ‘Hindi Fortnight Incentive Scheme’ continued during the year under which the officers / employees doing maximum work in Hindi during the Hindi month were awarded. The incentive scheme of the Department “SOLIS” introduced last year had been revised.



- During the year various Centres / Units of the Department conducted technical seminars in Hindi on various subjects. Thirteen technical seminars were organised. All the centres also organised a session on official language during their technical seminars. Eleven Official Language seminars were conducted. Seminar Souvenir in electronic / book form were also brought out.
- A technical Seminar in Hindi on “Antararashtriya Pariprekshya mein Bharatiya Antariksh Karyakram” (Indian Space Programme - Global Perspective) and a Rajbhasha Technical Seminar on “Antariksh Vibhag mein takniki sahitya evam gatividhiyan” (Hindi Technical literature and Activities of Department of Space) were conducted by the DOS / ISRO for the Bengaluru based Units for the year 2016 including Branch Secretariat, ILC (Mumbai), ANTRIX, ISTRAC and MCF.
- The employees of DOS / ISRO Centres / Units have also participated in the activities on progressive use of Hindi organised by various voluntary organisations and also by Town OLIC.
- Hindi Implementation introduced as a part of Induction Programme in all the major Centres of DOS / ISRO continued during the year.
- During the year, the work regarding the updation of Space Science Glossary by the Department in collaboration with CSTT, New Delhi was completed and 5000 copies of the Glossary were printed and distributed in all Centres / Units. The Glossary has been made available in electronic form and uploaded on the website.
- The Department has taken up the task of inclusion of Hindi in COINS, the web version of COWAA. In this regard the forms pertaining to Accounts have been completed and the work in respect of the forms in the area of Administration and Purchase is in progress.

### Awards:

- For Best implementation of Official Language policy of the GOI, Department of Space was awarded the “Rajbhasha Kirti Puraskar” (II Prize) by His Excellency the President of India in a function organised at Rashtrapati Bhawan, New Delhi on September 14, 2016 that was received by the Secretary, DOS / Chairman, ISRO.
- Various Centres / Units of the Department have been awarded prizes under their respective Town OLICs during the year 2016-17 for the best Hindi Implementation work. SAC, Ahmedabad got Rolling Shield, VSSC, Thiruvananthapuram, DECU, Ahmedabad and MCF, Hassan got First Prize, ISTRAC, Bengaluru got Second Prize, LEOS, Bengaluru got Consolation Prize and RRSC(S), Bengaluru got Certificate.





**Hon'ble President of India giving away "RAJBHASHA KIRTI AWARD"  
to Mr A.S. Kiran Kumar Secretary, Department of Space**



## International Cooperation

International cooperation through sharing of knowledge and infrastructure beyond the boundaries is an integral part of developing space technology and applications in many nations. Ever since the inception, Indian space programme pursues bilateral and multilateral cooperative relations with space agencies and space related bodies. Indian Space Research Organisation (ISRO) of the Department of Space (DOS) carried out many activities in 2016-17, which were aimed at intensifying space relations with traditional partners and establishing new relations with other nations in the peaceful uses of outer space. The activities include carrying out joint activities of mutual interest; sharing expertise in the applications of space technology and participation in international events dealing with space.

Space cooperative documents are signed with space agencies of 39 countries and 4 multinational bodies, namely, Afghanistan, Argentina, Australia, Brazil, Brunei Darussalam, Bulgaria, Canada, Chile, China, Egypt, European Centre for Medium Range Weather Forecasts (ECMWF), European Organisation for Exploitation of Meteorological Satellites (EUMETSAT), European Space Agency (ESA), France, Germany, Hungary, Indonesia, Israel, Italy, Japan, Kazakhstan, Kuwait, Mauritius, Mexico, Mongolia, Myanmar, Norway, Peru, Republic of Korea, Russia, Saudi Arabia, South Asian Association for Regional Cooperation (SAARC), Spain, Sweden, Syria, Thailand, The Netherlands, Ukraine, United Arab Emirates (UAE), United Kingdom (UK), United States of America (USA), Venezuela and Vietnam.

The cooperative agreements signed during this year are: (i) Implementing Arrangement (IA) between ISRO and French National Space Agency (CNES) related to cooperation in definition studies on a future joint Thermal Infrared (TIR) earth observation mission; (ii) IA between ISRO and CNES related to cooperation concerning hosting CNES's ARGOS onboard ISRO's OCEANSAT-3; (iii) Letter of Intent (LOI) between ISRO and CNES for cooperation in space exploration; (iv) Memorandum of Understanding (MoU) between ISRO and the UAE Space Agency on cooperation in the exploration and use of outer space for peaceful purposes; (v) LOI between ISRO and Japan Aerospace Exploration Agency (JAXA) concerning a joint Earth Observation mission; (vi) MoU between ISRO and United States Geological Survey (USGS) for cooperation in the exchange and use of U.S. Land Remote Sensing Satellite; (vii) Framework Agreement between India and Viet Nam on cooperation in the exploration and uses of outer space for peaceful purposes; (viii) MoU between India and Afghanistan on cooperation in the peaceful uses of outer space; (ix) The Charter for establishing ISRO-NASA Working Group on Heliophysics; and (x) MoU between ISRO and ROSCOSMOS (Russia) on mutual allocation of ground measurement gathering stations for NavIC and GLONASS; (xi) IA between ISRO and NASA for cooperation on the utilisation of data from International Space Station (ISS) Rapid Scatterometer and ISRO SCSATSAT-1 Scatterometer; and (xii) MoU between ISRO and JAXA concerning cooperation in the field of outer space.

Space cooperation between India and France made significant progress in 2016 with the signing of cooperative documents in newer areas. Definition studies towards realisation of a joint earth observation satellite mission with Thermal Infrared Imager are currently on. Technical team from both sides are also working on the modalities of integrating CNES's ARGOS data collection instrument in



ISRO's Oceansat-3 satellite. To expand cooperation beyond earth observation, a 'Planetary Exploration Joint Working Group' has been established, which will look at the possibilities of cooperation in future planetary exploration missions. Indian and French scientists are also working on a joint Ka-band propagation experiment using signals from GSAT-14 satellite and ground instruments. Considering the valuable information provided by the scientific instruments onboard the ISRO-CNES Joint satellite 'Megha Tropiques', both agencies have agreed to extend the validity of 'Megha Tropiques MoU' for four years, until December 2020.

ISRO and NASA teams made significant progress in realising the joint microwave remote sensing satellite for earth observation, "NISAR (NASA-ISRO Synthetic Aperture Radar)". The project has successfully cleared many internal reviews and has transitioned from 'formulation' to 'implementation' stage. A joint airborne campaign to collect scientific data over diverse eco-system was carried out using NASA's instrument and ISRO's aircraft. Necessary documents have been signed to enable exchange of earth observation data collected by India's Resourcesat-2 data and USA's LANDSAT-8 satellite data. Apart from making progress in technical discussions for cooperation in Mars exploration, both agencies have established a new Joint Working Group to explore cooperation possibilities in Heliophysics (study of the Sun and the interaction between the Sun and the Earth).

As a follow-up to the new cooperative MoU signed in January 2015, ISRO and ROSCOSMOS have signed an Implementation MoU to facilitate the establishment of ground stations on each other's territory to support their respective navigation satellite systems. Both sides have also made significant progress in their technical discussions to establish liquid propulsion ( $N_2O_4$ ) production plant in India.

The space agencies of India and Japan have agreed to further enhance cooperation by signing a new MoU, which enables inclusion of satellite navigation and planetary exploration as additional areas of cooperation. Both agencies have also agreed to conduct a joint experiment to study Venus atmosphere by collecting signals from JAXA's Akatsuki mission by ISRO's ground stations (IDSN). JAXA has agreed to support ISRO to establish a ground station in Japan to support NavIC satellite constellation.

As a follow-up to the MoU on space cooperation signed in October 2014, space agencies of India and Mexico jointly organised a workshop on "Best Practices in the use of Space Technology for Disaster Management" during July 13-15, 2016 in Mexico City.

Towards establishing new relations, ISRO hosted meetings with delegations from Bangladesh, Switzerland, and Sri Lanka. Proposal for cooperation with Tajikistan, Afghanistan, Armenia and Uzbekistan were submitted to Ministry of External Affairs. ISRO officials have been sent to major events in Moro

Prominent visitors to ISRO Centres in 2016-17 include Canadian Minister for Innovation, Science and Economic Development, US Congressmen, Ministerial delegation from Pacific Island Countries (PICs), NASA Administrator, CNES President, JPL Director, Ambassador of European Union (EU) delegation to India, Ambassador of France to India, Ambassador of Germany to India and Australian High Commissioner to India.



Significant progress has been made (i) in realising 'South Asia Satellite', which will provide satellite communication services to South Asian nations and also across the region; and (ii) in implementing 'India- Association of South East Asian Nations (ASEAN) space cooperation project', which will enable sharing of data from Indian satellites with ASEAN member nations for a variety of applications including disaster management support and also to provide training in space science, technology and applications.

In the field of capacity building, ISRO continues to share its facilities, expertise in the application of space science and technology by conducting short-term and long-term courses through Indian Institute of Remote Sensing (IIRS) and the United Nations (UN) affiliated Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP) at Dehradun. As of now, there are more than 1600 beneficiaries from 52 countries. A short-course on 'Satellite Engineering and Small satellites' was conducted for the benefit of officials from ASEAN member nations.

Several international space events including (i) 'UN / India Workshop on the use of earth observations data in disaster management and risk reduction' in March; (ii) '10th SPIE Asia-Pacific Remote Sensing Symposium' in April; (iv) '5<sup>th</sup> edition of 'Bengaluru Space Exhibition' in September; and (v) 'Asia Pacific Space Leaders Forum on Disaster Risk Reduction' in November were organised in this year. In 2017-18, India will be hosting the 38<sup>th</sup> Asian Remote Sensing Conference (ACRS) at New Delhi and 24<sup>th</sup> Session of Asia Pacific Regional Space Agency Forum (APRSAF) at Bangalore, among other international space events.

ISRO and CNES jointly organised a reception on April 03, 2016 at New Delhi to highlight the importance of space inputs for climate change studies and to support government decisions taken during Committee of Parties (COP)-21 meeting at Paris. Heads of space agencies and their representatives from India, France, USA, Japan, Mexico and Europe (ESA and EUMETSAT) have attended this event and approved the principles of a Declaration underlining the commitments made by the space sector to evolve space-based operational tools combining in-situ measurements and increased computing resources and to develop new technologies to be flown in space or encourage their research community to contribute actively with new models. Cooperation to cross-calibrate instruments and cross-validate their measurements, in order to achieve an international, independent system for estimating the emissions of all world nations based on internationally accepted data, thus creating a level playing field and an independent basis for further reductionss was also stressed at this meeting.



India participates in international disaster management mechanisms including International Charter "Space and Major Disasters", Sentinel Asia programme of APRSAF, UN Economic and Social Commission for Asia and the Pacific (ESCAP) and UN Platform for Space based Information for Disaster management and Emergency Response (UNSPIDER). ISRO provided satellite data to all the 22 requests, globally under International Charter and for 16 disasters in 9 nations in Asia Pacific region under Sentinel Asia programme. India, as a member of the International COSPAS-SARSAT system for search and rescue operations, provides search and rescue support to India and seven neighbouring countries, namely Bangladesh, Bhutan, Maldives, Nepal, Seychelles, Sri Lanka and Tanzania. Under the Regional Cooperative Mechanism of UNESCAP, India is offering technical support to Myanmar and Nepal to establishing agricultural drought monitoring mechanism.

ISRO continues to play an active role in the deliberation of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and India is currently chairing the Scientific & Technical Sub Committee (for the year 2016). ISRO also actively participates in the meetings of prominent multilateral fora including International Astronautical Federation (IAF), International Academy of Astronautics (IAA), International Institute of Space Law (IISL), Committee on Earth Observation Satellites (CEOS), International Society for Photogrammetry and Remote Sensing (ISPRS), Coordination Group on Meteorological Satellites (CGMS), Space Frequency Coordination Group (SFCG), International Committee for Global Navigation Satellite Systems (ICG), Committee on Space Research (COSPAR), International Space Exploration Coordination Group (ISECG) and Inter-Agency Space Debris Coordination Committee (IADC).

Prof U R Rao, former Chairman, ISRO and Secretary, Department of Space was honoured by the International Astronautical Federation (IAF) with the "2016 IAF Hall of Fame" Award, for his outstanding contribution to the progress of astronautics within the framework of the IAF activities.



**Chairman, UAESA and Chairman, ISRO / Secretary, DOS  
exchanging the MoU in the presence of Hon'ble Prime Minister**



## ‘Space’ In Parliament

Indian Space Programme continued to attract the attention of both the Houses of Parliament. Questions were answered in Parliament during the year 2016 as shown below:-

Questions	Budget Session		Monsoon Session		Total	
	7 <sup>th</sup> session-16 <sup>th</sup> Lok Sabha	238 <sup>th</sup> session of Rajya Sabha	9 <sup>th</sup> Session-16 <sup>th</sup> Lok Sabha	240 <sup>th</sup> Session of Rajya Sabha	L.S.	R.S.
<b>Starred Questions</b>	02	0	02	0	04	0
<b>Unstarred Questions</b>	41	19	11	08	52	27
<b>Total</b>	43	19	13	08	56	27

The Questions were related to GSLV and Cryogenic Technology, Regional Positioning System / IRNSS, Space Industry Park / Enclave, Space Technologies, International Space Treaty, Industry participation in space programme, Manned Space Mission, Mars Orbiter Mission, BHUVAN Portal, BRICS Satellite, Private partnership in space industry, Space Projects, Astrobiology Mission, Scramjet Engine, Disaster Management, Reusable Launch Vehicle, Funds for Space Research and Space Programmes, Participation of students in Space Research, EDUSAT, Space Act, Satellites launched by India and accruals from Sending Satellites to Space, NISAR mission etc.

During the year 2016, till October, eight Parliamentary Committees have visited and held discussion with representatives of various Centres / Units of the Department of Space.



## Space Programme Publicity

India has made significant progress in the important areas of space science as well as technology and space based services are touching all facets of human life in the country. Creating awareness among the general public, especially students, about the benefits that have accrued from India's applications driven space programme to the society and the significant progress made by the country in space science and technology has been given utmost importance. Media campaigns on important events, campaign through social media, webcasting of launches, organisation of exhibitions, educational activities like lectures, interactive sessions with students, quiz programmes, water rocket making and launching events, publications, video documentaries, SAKAAR – an Augmented Reality Application for Android devices, etc., have helped in not only keeping the public abreast of the latest developments in our space programme but also to evoke interest in them on the nuances of space science and technology.



Visit of Students to Space Expo during World Space Week at Thiruvananthapuram

### Publicity Through Media

#### Print and Electronic Media

Doordarshan and many private TV channels provided prominent live coverage to the launch of PSLV-C32 / IRNSS-1F on March 10, 2016, PSLV-C33 / IRNSS-1G on April 28, 2016, PSLV-C34 / Cartosat-2 Series Satellite on June 22, 2016, GSLV-F05 / INSAT-3DR on September 08, 2016, PSLV-C35 / SCATSAT-1 on September 26, 2016 and PSLV-C36 / Resourcesat-2A on December 07, 2016 from SDSC SHAR, Sriharikota. For these launches, media from Chennai, Nellore, Tirupati and Sullurpetta were invited to Satish Dhawan Space Centre, Sriharikota to witness the launch. Additionally, Doordarshan (DD)



covered the launch of India's communication satellite GSAT-18 by European Ariane 5 VA231 Live. But, the event for which local, national and even international media continued to provide conspicuous coverage was the successful Mars Orbiter Mission (MOM). In its November 2016 issue, the National Geographic Magazine printed the image of Mars disc taken by India's Mars Orbiter Mission spacecraft and National Geographic TV channel repeatedly telecast a special one hour documentary on MOM done earlier.

Foreign media also covered the two PSLV commercial launches (PSLV-C34 and PSLV-C35 in which foreign payloads were carried as copassenger satellites). Special video capsules on the Indian space programme including those on PSLV, IRNSS, GSLV-F05 / INSAT-3DR, GSAT-18, Cartosat-2 Series Satellite, SCATSAT-1 and Resourcesat-2A and PSLV commercial missions were produced and telecast.

Besides media coverage on specific events of importance, several articles have appeared in various regional and national newspapers and magazines about the Indian space programme, especially on MOM. This apart, many news agencies, newspapers and TV channels made and telecast programmes on Indian Space activities, highlighting the accomplishments of the Indian Space Programme in the context of MOM progress and PSLV commercial launches. Print and electronic media provided good coverage for the maiden flight tests of RLV-TD as well as Scramjet technology demonstrator, both of which are advanced propulsion technology initiatives of ISRO.

'SAKAAR', an Augmented Reality application for Android devices that helps the users, especially students, to better visualise ISRO launch vehicle, satellite and applications programmes, was publicised during ISRO outreach programmes. Information on the Indian space programme is available to public through the highly interactive and user friendly ISRO website <http://www.isro.gov.in>. The Website also provides DOS Annual Report, Space India, press releases, special publications, story of the week, SAKAAR, employment opportunities, RTI related information, etc.



LPSC Onam Pageantry 2016



## Social Media

Considering the importance of social media during contemporary times, the official ISRO Facebook on Mars Orbiter Mission was launched. Based on the encouraging response, an official ISRO facebook was also subsequently launched. This was followed by the launch of an official ISRO twitter to inform about important events and developments concisely. These social media outlets are also being used to disseminate information about the various developments in the Indian space programme.

## Exhibitions

During the year ISRO organised many exhibitions at national and international conferences, important public congregations like cultural festivals, trade fairs and events and also at academic institutions. Exhibitions and many other outreach programmes were organised by ISRO Centres on important occasions like National Science Day and World Space Week in which thousands of students actively participated. Exhibitions and various other outreach events were also organised in association with Non-Governmental Organisations in various places and at prestigious events. A total of 29 exhibitions were organised during 2016. A large number of scientists, academicians and students from India as well as delegates from abroad visited many of these exhibitions.



Curious children at an ISRO Exhibition in Chandigarh



## Right to Information

Right To Information (RTI) Act 2005 is implemented in the Department with strict compliance to the requirements of the Act by identifying Central Public Information Officers (CPIO) for receiving applications and dissemination of information, Assistant Public Information Officers (APIOs) for receiving applications, First Appellate Authority for disposal of stage one appeals and Transparency Officer. As required under the Act, DOS has published the requisite information on the web page <http://www.isro.gov.in/right-to-information>

The following information is available on the website:

- Organisation, functions and duties
- Powers and duties of the Officers and Employees
- Procedures followed in the decision making process, including channels of supervision and accountability
- Norms set by the Department of Space for the discharge of its functions
- Rules, regulations, instructions, manuals and records of the Department of Space used by its employees for discharging their functions.
- Statement of the categories of documents held by the Department of Space or under its control
- Particulars of arrangements for consultation with or representation by the public in relation to the formulation of policies
- Statement of Boards, Councils, Committees and other Bodies and as to whether meetings of such boards, etc., are open to public, or the minutes of such meetings are accessible to public.
- Directory of officers holding functional designations.
- Monthly remuneration received by DOS / ISRO Officers & employees
- Budget 2015-16 of the Department of Space.
- Manner of execution of subsidy programmes and details of beneficiaries of such programmes
- Particulars of recipients of concessions, permits or authorisations granted by the Department of Space
- Particulars of facilities available to citizens for obtaining information on Department of Space / ISRO
- DOS Purchase Manual-2015
- Transfer Policy for the administrative cadre.
- Implementation of RTI Act, 2005, status as on July-September 2016
- Names, designations and other particulars of the Public Information Officers, Assistant Public Information Officers.

During the period January 2016 to December 2016, 882 applications were received and information were disseminated under the provisions of the RTI Act. 130 Appeals were received by the First Appellate Authority and 8 appellants approached the Second Appellate Authority, i.e., Central Information Commission.



## Audit Observations

### (A) Status of the Action Taken Note (ATN)

Sl. No	Year	No. of Paras / PA reports on which ATNs have been submitted to PAC after vetting by Audit	Details of the Paras / PA reports on which ATNs are pending			
			No. of ATNs not sent by the Ministry even for the 1st time	No. of ATNs sent by the Ministry and awaiting vetting by Audit	No. of ATNs sent but returned with observations and Audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by audit but have not been submitted by the Ministry to PAC
1	2	3	4	5	6	7
1.	Chapter V of Report No.9 of 2006 Non-Tax Receipts-Issues relating to receipts of DOS	Nil	Nil	One	Nil	Nil
2.	Report No.16 of 2011-12 (Para No19.1) Idle investment on development of a linac tube)	One	Nil	Nil	Nil	Nil
3.	Report No. 4 of 2012-2013 Hybrid satellite digital multimedia broadcasting service agreement with Devas	Nil	Nil	One	Nil	Nil
4.	Report No. 13 of 2012-13 Avoidable payment of demand charges	One	Nil	Nil	Nil	Nil
5.	Report No. 22 of 2013 (Para No. 3.1) Edusat Utilisation Programme	Nil	Nil	One	Nil	Nil



Sl. No	Year	No. of Paras / PA reports on which ATNs have been submitted to PAC after vetting by Audit	Details of the Paras / PA reports on which ATNs are pending			
			No. of ATNs not sent by the Ministry even for the 1st time	No. of ATNs sent by the Ministry and awaiting vetting by Audit	No. of ATNs sent but returned with observations and Audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by audit but have not been submitted by the Ministry to PAC
1	2	3	4	5	6	7
6.	Report No. 22 of 2013 (Para No. 3.2) Parking of foreign Satellite in Indian Administration coordinated orbital slot.	One	Nil	Nil	Nil	Nil
7.	Report No. 22 of 2013 (Para No. 3.3) Loss due to unsafe transport and belated insurance of consignment	Nil	Nil	One	Nil	Nil
8	Report No. 22 of 2014 Management of satellite capacity for DTH service by Department of Space	One	Nil	Nil	Nil	Nil
9	Report No. 22 of 2014 (Para No. 4.1) Inordinate delay in realisation of SRE-2 mission	Nil	Nil	One	Nil	Nil
10	Report No. 22 of 2014 (Para No.4.2) Loss in allocation of satellite Capacity	Nil	Nil	One	Nil	Nil



Sl. No	Year	No. of Paras / PA reports on which ATNs have been submitted to PAC after vetting by Audit	Details of the Paras / PA reports on which ATNs are pending			
			No. of ATNs not sent by the Ministry even for the 1st time	No. of ATNs sent by the Ministry and awaiting vetting by Audit	No. of ATNs sent but returned with observations and Audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by audit but have not been submitted by the Ministry to PAC
1	2	3	4	5	6	7
11	Report No. 22 of 2014 (Para No. 4.3) Avoidable expenditure due to improper contract management	One	Nil	Nil	Nil	Nil
12	Report No. 27 of 2014 (Para No. 4.4) Infructuous expenditure on procurement of components	One	Nil	Nil	Nil	Nil
13	Report No.30 of 2015 (Para No. 5.1) Implementation incentive scheme	Nil	Nil	Nil	One	Nil
14	Report No.30 of 2015 (Para No. 5.3) Avoidable payment of electricity charges	Nil	Nil	One	Nil	Nil
15	Report No.12 of 2016 (Para No.5.1) Computerisation in administration, finance and related areas	Nil	Nil	One	Nil	Nil
16	Report No.12 of 2016 (Para No.5.2) Implementation of Telemedicine Programme	Nil	Nil	One	Nil	Nil



Sl. No	Year	No. of Paras / PA reports on which ATNs have been submitted to PAC after vetting by Audit	Details of the Paras / PA reports on which ATNs are pending			
			No. of ATNs not sent by the Ministry even for the 1st time	No. of ATNs sent by the Ministry and awaiting vetting by Audit	No. of ATNs sent but returned with observations and Audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by audit but have not been submitted by the Ministry to PAC
1	2	3	4	5	6	7
17	Report No.12 of 2016 (Para No.5.3) Wasteful expenditure on material for propellant tanks	Nil	Nil	One	Nil	Nil
18	Report No.12 of 2016 (Para No.5.4) Loss due to delayed commissioning of equipment	Nil	Nil	One	Nil	Nil
19	Report No.12 of 2016 (Para No.5.5) Unfruitful expenditure on consultancy services	Nil	Nil	One	Nil	Nil
20	Report No.12 of 2016 (Para No.5.6) Non-levy of labour welfare cess on construction work payment	Nil	Nil	One	Nil	Nil



**(B) Summary of important audit observations during 2016**

**a) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.1 titled “Computerisation in administration, finance and related areas”**

The Computerised Working in Administrative Areas (COWAA) package developed by the Department of Space lacked proper inbuilt validation checks and application controls. Certain business rules were not incorporated. Data entry into the system was not regular. Consequently, information generated from the system was incomplete, inaccurate and inconsistent leading to poor data integrity and significant dependence on manual operations, which defeated the purpose of working in a computerised environment.

**b) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.2 titled “Implementation of Telemedicine Programme”**

The Department could not ensure effective utilisation of satellite communication for providing health services to patients in rural and remote areas even after incurring expenditure of ₹30.18 crore. Out of 389 networks established, only 150 were operational. In addition, selection of beneficiary hospitals was irregular, satellite capacity for remote and interior areas of the country was inadequate and Ka-band ground terminals worth ₹14.12 crore could not be utilised.

**(c) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.3 titled “Wasteful expenditure on material for propellant tanks”**

The Department did not prepare a definite time based action plan for phasing out a material found to cause failures in propellant tanks of launch vehicles. This resulted in wasteful expenditure of ₹3.49 crore towards the cost of one propellant tank and 65 tonnes of the material kept in stock that was ultimately quarantined.

**(d) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.4 titled “Loss due to delayed commissioning of equipment”**

The Department waived off liquidated damages for delay in supply of a system onboard a satellite having limited operational life and thereby extended undue benefit to the contractor to the extent of ₹1.16 crore. Besides, the delay resulted in proportionately lesser use of its operational life.

**(e) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.5 titled “Unfruitful expenditure on consultancy services”**

The Department hired a firm for providing architectural and other consultancy services for construction of a building in New Delhi without following due diligence in selection of the firm. The firm could not comply with the initial design requirements of the statutory authority and DOS rescinded the contract and decided to carry out the work in-house. Consequently, payment of ₹1.04 crore made to the firm was rendered unfruitful.

**(f) C&AG Report Union Government, Scientific Departments Report No. 12 of 2016 Para 5.6 titled “Non-levy of labour welfare cess on construction work payment”**

VSSC failed to deduct statutory labour welfare cess to the extent of ₹71.23 lakh from payments made to contractors for execution of civil works.



## Milestones

### 1962

- Indian National Committee for Space Research formed and works on establishing Thumba Equatorial Rocket Launching Station (TERLS) started

### 1963

- First sounding rocket launch from TERLS (November 21, 1963)

### 1965

- Space Science and Technology Centre (SSTC) established in Thumba

### 1967

- Experimental Satellite Communication Earth Station (ESCES) set up at Ahmedabad

### 1968

- TERLS dedicated to the United Nations (February 2, 1968)

### 1969

- Indian Space Research Organisation (ISRO) formed (August 15, 1969)

### 1972

- Space Commission and Department of Space (DOS) set up. ISRO brought under DOS (June 1, 1972)

### 1972-76

- Air-borne remote sensing experiments

### 1975

- ISRO becomes Government Organisation (April 1, 1975)
- First Indian Satellite, Aryabhata, launched (April 19, 1975)

### 1975-76

- Satellite Instructional Television Experiment (SITE) conducted

### 1977-79

- Satellite Telecommunication Experimental Project (STEP) carried out



## 1979

- Bhaskara-I, an experimental satellite for earth observations, launched (June 7, 1979)
- First Experimental launch of SLV-3 with Rohini Technology Payload onboard (August 10, 1979). Satellite could not be placed in orbit

## 1980

- Second Experimental launch of SLV-3. Rohini satellite successfully placed in orbit (July 18, 1980)

## 1981

- First developmental launch of SLV-3. RS-D1 placed in orbit (May 31, 1981)
- APPLE, an experimental geostationary communication satellite successfully launched (June 19, 1981)
- Bhaskara-II launched (November 20, 1981)

## 1982

- INSAT-1A launched (April 10, 1982). Deactivated on September 6, 1982

## 1983

- Second developmental launch of SLV-3. RS-D2 placed in orbit (April 17, 1983)
- INSAT-1B launched (August 30, 1983)

## 1984

- Indo-Soviet manned space mission (April 1984)

## 1987

- First developmental launch of ASLV with SROSS-1 satellite onboard (March 24, 1987). Satellite could not be placed in orbit

## 1988

- Launch of first operational Indian Remote Sensing satellite, IRS-1A (March 17, 1988)
- Second developmental launch of ASLV with SROSS-2 onboard (July 13, 1988). Satellite could not be placed in orbit
- INSAT-1C launched (July 22, 1988). Abandoned in November 1989

## 1990

- INSAT-1D launched (June 12, 1990)



### 1991

- Launch of second operational Remote Sensing satellite, IRS-1B (August 29, 1991)

### 1992

- Third developmental launch of ASLV with SROSS-C on board (May 20, 1992). Satellite placed in orbit
- INSAT-2A, the first satellite of the indigenously-built second-generation INSAT series, launched (July 10, 1992)

### 1993

- INSAT-2B, the second satellite in INSAT-2 series, launched (July 23, 1993)
- PSLV-D1, the first developmental launch of PSLV with IRS-1E onboard (September 20, 1993). Satellite could not be placed in orbit

### 1994

- Fourth developmental launch of ASLV with SROSS-C2 onboard (May 4, 1994). Satellite placed in orbit
- PSLV-D2, the second developmental launch of PSLV with IRS-P2 onboard (October 15, 1994). Satellite successfully placed in Polar Sun Synchronous Orbit

### 1995

- INSAT-2C, the third satellite in INSAT-2 series, launched (December 7, 1995)
- Launch of third operational Indian Remote Sensing Satellite, IRS-1C (December 28, 1995)

### 1996

- PSLV-D3, the third developmental launch of PSLV with IRS-P3 onboard (March 21, 1996). Satellite placed in Polar Sun Synchronous Orbit

### 1997

- INSAT-2D, fourth satellite in INSAT-2 series, launched (June 4, 1997). Becomes in-operable on October 4, 1997. (An in-orbit satellite, ARABSAT-1C, later renamed INSAT-2DT, was acquired in November 1997 to partly augment INSAT system)
- PSLV-C1, the first operational launch of PSLV with IRS-1D onboard (September 29, 1997). Satellite placed in orbit

### 1998

- INSAT system capacity augmented with the readiness of INSAT-2DT acquired from ARABSAT (January 1998)



## 1999

- INSAT-2E, the last satellite in the multipurpose INSAT-2 series, launched by Ariane from Kourou, French Guyana (April 3, 1999)
- Indian Remote Sensing Satellite, IRS-P4 (OCEANSAT-1), launched by Polar Satellite Launch Vehicle (PSLV-C2) along with Korean KITSAT-3 and German DLR-TUBSAT from SDSC SHAR, Sriharikota (May 26, 1999)

## 2000

- INSAT-3B, the first satellite in the third generation INSAT-3 series, launched by Ariane from Kourou, French Guyana (March 22, 2000)

## 2001

- Successful flight test of Geosynchronous Satellite Launch Vehicle (GSLV-D1) on April 18, 2001 with an experimental satellite GSAT-1 onboard
- Successful launch of PSLV-C3 on October 22, 2001 placing three satellites – India's TES, Belgian PROBA and German BIRD into Polar Sun Synchronous Orbit

## 2002

- Successful launch of INSAT-3C by Ariane from Kourou, French Guyana (January 24, 2002)
- Successful launch of KALPANA-1 by ISRO's PSLV-C4 from SDSC SHAR (September 12, 2002)

## 2003

- Successful launch of INSAT-3A by Ariane from Kourou, French Guyana (April 10, 2003)
- Successful launch of GSLV-D2, the second developmental test flight of GSLV with GSAT-2 onboard from SDSC SHAR (May 8, 2003)
- Successful launch of INSAT-3E by Ariane from Kourou, French Guyana (September 28, 2003)
- Successful launch of Resourcesat-1 by ISRO's PSLV-C5 from SDSC SHAR (October 17, 2003)

## 2004

- GSLV-F01, the first operational flight of GSLV from SDSC SHAR. EDUSAT successfully placed in GTO (September 20, 2004)

## 2005

- Successful launch of Cartosat-1 and HAMSAT by PSLV-C6 from the newly established Second Launch Pad at SDSC SHAR (May 5, 2005)
- Successful launch of INSAT-4A by Ariane from Kourou, French Guyana (December 22, 2005)



## 2006

- GSLV-F02, the second operational flight of GSLV from SDSC SHAR with INSAT-4C onboard (July 10, 2006). The satellite could not be placed in orbit

## 2007

- PSLV-C7 successfully launches four satellites – India's Cartosat-2 and Space Capsule Recovery Experiment (SRE-1) as well as Indonesia's LAPAN-TUBSAT and Argentina's PEHUENSAT-1 (January 10, 2007)
- Successful recovery of SRE-1 after manoeuvring it to re-enter the earth's atmosphere and descend over the Bay of Bengal about 140 km East of Sriharikota (January 22, 2007)
- Successful launch of INSAT-4B by Ariane launch vehicle from Korou, French Guyana on March 12, 2007
- PSLV-C8 successfully launches an Italian satellite AGILE on April 23, 2007 under a commercial contract with Antrix Corporation
- Launch of GSLV-F04 with INSAT-4CR onboard from SDSC SHAR on September 2, 2007

## 2008

- PSLV-C10 successfully launches TECSAR satellite on January 21, 2008 under a commercial contract with Antrix Corporation
- PSLV-C9 successfully launches ten satellites on April 28, 2008: India's Cartosat-2A, Indian Mini Satellite-1 (IMS-1) and eight Nano Satellites for International Customers under a commercial contract with Antrix Corporation
- PSLV-C11 successfully launches Chandrayaan-1 spacecraft on October 22, 2008
- European Ariane-5 launch vehicle successfully launches W2M satellite on December 21, 2008 jointly built by Antrix / ISRO and EADS Astrium on a commercial basis

## 2009

- PSLV-C12 successfully launches RISAT-2 and ANUSAT, on April 20, 2009
- PSLV-C14 successfully launches OCEANSAT-2 and six nanosatellites for international customers under a commercial contract with Antrix Corporation (September 23, 2009)

## 2010

- Successful static testing of GSLV-Mk III Launch Vehicle's S200 Solid Propellant Booster Rocket Stage (January 24, 2010)
- GSLV-D3, the first launch of GSLV with indigenous Cryogenic Upper Stage and GSAT-4 satellite onboard. GSAT-4 could not be placed in orbit (April 15, 2010)
- PSLV-C15, the seventeenth flight of PSLV, successfully launches India's Cartosat-2B and STUDSAT, Algeria's ALSAT-2A, Canada's NLS-1 and NLS-2 on (July 12, 2010).
- Successful Static Testing of GSLV-MkIII Launch Vehicle's L110 Liquid Core Stage (September 8, 2010)



- European Ariane-5 launch vehicle successfully launches HYLAS satellite on November 27, 2010 jointly built by Antrix / ISRO and EADS Astrium on a commercial basis
- GSLV-F06, the seventh launch of GSLV with GSAT-5P satellite onboard, could not place the satellite in orbit (December 25, 2010)

## 2011

- PSLV-C16 successfully launches India's Resourcesat-2, YOUTHSAT and X-SAT from Singapore on April 20, 2011
- GSAT-8 Communication Satellite launched by Ariane launcher from Kourou, French Guiana on May 21, 2011
- PSLV-C17 successfully launches GSAT-12 Communication Satellite on July 15, 2011
- Second successful static testing of S-200 booster to be used in GSLV-Mk III on September 4, 2011
- PSLV-C18 successfully launches the Indo-French satellite Megha-Tropiques and three co-passenger satellites – Jugnu from IIT, Kanpur, SRMSat from SRM University, Chennai and VesselSat-1 from Luxembourg – on October 12, 2011

## 2012

- PSLV, in its twenty first flight (PSLV-C19), launches India's first Radar Imaging Satellite (RISAT-1) from Sriharikota on April 26, 2012
- In its twenty second flight (PSLV-C21), PSLV successfully launches French earth observation satellite SPOT-6 along with Japanese micro-satellite PROITERES from Sriharikota on September 09, 2012
- India's heaviest communication satellite, GSAT-10, successfully launched by Ariane-5 VA 209 from Kourou, French Guiana on September 29, 2012

## 2013

- PSLV, in its twenty third flight (PSLV-C20), successfully launches Indo-French Satellite SARAL along with six smaller satellites from abroad from Sriharikota on February 25, 2013
- PSLV, in its twenty fourth flight (PSLV-C22), successfully launches India's first dedicated navigation satellite IRNSS-1A from Sriharikota on July 01, 2013
- India's advanced weather satellite INSAT-3D successfully launched by Ariane-5 VA-214 from Kourou, French Guiana on July 26, 2013
- India's advanced communication satellite GSAT-7 successfully launched by Ariane-5 VA-215 from Kourou, French Guiana on August 30, 2013
- Mars Orbiter Mission, the India's first interplanetary mission to planet Mars, successfully launched by PSLV-C25 from Sriharikota on November 05, 2013
- Trans Mars Injection Manoeuvre performed on Mars Orbiter Spacecraft on December 01, 2013 to place it in Mars Transfer Trajectory



## 2014

- In its first successful flight with indigenous Cryogenic Upper Stage, GSLV-D5 successfully places GSAT-14 into GTO on January 05, 2014
- PSLV, in its twenty sixth flight (PSLV-C24), successfully launches IRNSS-1B, the second satellite of the Indian Regional Navigation Satellite System (IRNSS) from SDSC SHAR, Sriharikota on April 04, 2014
- PSLV-C23 Successfully launches French Earth Observation Satellite- SPOT 7 and four other co-passenger satellites from SDSC SHAR, Sriharikota on June 30, 2014
- India's Mars Orbiter Spacecraft successfully enters into an orbit around planet Mars on September 24, 2014
- PSLV, in its twenty eighth flight (PSLV-C26) successfully launches IRNSS-1C, the third satellite of the Indian Regional Navigation Satellite System (IRNSS) from SDSC SHAR, Sriharikota on October 16, 2014
- India's communication satellite, GSAT-16 successfully launched by the Ariane-5 VA221 from Kourou, French Guiana on December 07, 2014
- The first experimental suborbital flight (LVM3-X / CARE) of India's next generation launch vehicle LVM3 (GSLV Mk-III) was successfully conducted from Satish Dhawan Space Centre SHAR, Sriharikota on December 18, 2014. CARE module carried onboard to a height of 126 km successfully recovered later

## 2015

- PSLV-C27 Successfully Launches India's Fourth Navigation Satellite IRNSS-1D on March 28, 2015 from Satish Dhawan Space Centre SHAR, Sriharikota.
- PSLV-C28 successfully launches three identical DMC3 commercial Earth Observation Satellites, along with two smaller satellites from United Kingdom, into a polar Sun Synchronous Orbit on July 10, 2015 from Satish Dhawan Space Centre SHAR, Sriharikota.
- Geo-Synchronous Satellite Launch Vehicle (GSLV-D6), equipped with the indigenous Cryogenic Upper Stage (CUS), successfully launches 2117 kg GSAT-6, into a GTO on August 27, 2015 from Satish Dhawan Space Centre SHAR, Sriharikota.
- AstroSat, India's first dedicated astronomy satellite successfully launched by PSLV-C30 on September 28, 2015 from Satish Dhawan Space Centre SHAR, Sriharikota. Along with AstroSat, six satellites from international customers - LAPAN-A2 of Indonesia, NLS-14 (Ev9) of Canada and four identical LEMUR satellites of USA – were also launched by this PSLV flight
- The 3164 kg GSAT-15 carrying Ku-band transponders and GAGAN payload launched successfully by the European Ariane-5 VA-227 from Kourou, French Guiana on November 11, 2015
- In its thirty second flight conducted from SDSC SHAR, Sriharikota on December 16, 2015, PSLV-C29 successfully launches six satellites from Singapore (400 kg TeLEOS-1 as primary satellite and other Five co-passenger payloads).



## 2016

- The Polar Satellite Launch Vehicle, in its 33<sup>rd</sup> flight (PSLV-C31), launches IRNSS-1E, the fifth satellite of the Indian Regional Navigation Satellite System (IRNSS) on January 20, 2016 from SDSC SHAR, Sriharikota.
- The Polar Satellite Launch Vehicle, in its 34<sup>th</sup> flight (PSLV-C32), launches IRNSS-1F, the sixth satellite of the Indian Regional Navigational Satellite System (IRNSS) on March 10, 2016 from SDSC SHAR, Sriharikota.
- The Polar Satellite Launch Vehicle, in its 35<sup>th</sup> flight (PSLV-C33), launches IRNSS-1G, the seventh satellite of the Indian Regional Navigation Satellite System (IRNSS) into a Sub-Geosynchronous Transfer Orbit (Sub-GTO) on April 28, 2016 from SDSC SHAR, Sriharikota.
- India's Reusable Launch Vehicle-Technology Demonstrator (RLV-TD), successfully flight tested on May 23, 2016 from SDSC SHAR, Sriharikota. RLV-TD is one of the most technologically challenging endeavors of ISRO towards developing essential technologies for a fully reusable launch vehicle to enable low cost access to space.
- India's Polar Satellite Launch Vehicle, in its 36<sup>th</sup> flight (PSLV-C34), launches the 727.5 kg Cartosat-2 Series Satellite for earth observation and 19 co-passenger satellites together weighing about 560 kg at lift-off into a 505 km polar Sun Synchronous Orbit (SSO) on June 22, 2016 from Sriharikota. The co-passenger satellites are from USA, Canada, Germany and Indonesia as well as two satellites (SATHYABAMASAT and SWAYAM) from Indian University / Academic Institute.
- The first experimental mission of ISRO's Scramjet Engine towards the realisation of an Air Breathing Propulsion System was successfully conducted on August 28, 2016 from Satish Dhawan Space Centre SHAR, Sriharikota.
- India's Geosynchronous Satellite Launch Vehicle (GSLV), in its tenth flight (GSLV-F05) launches INSAT-3DR, an advanced weather satellite, weighing 2,211 kg into a Geostationary Transfer Orbit (GTO) on September 08, 2016 from SDSC SHAR, Sriharikota.
- India's Polar Satellite Launch Vehicle, in its 37<sup>th</sup> flight (PSLV-C35), launches the 371 kg SCATSAT-1 for weather related studies and seven co-passenger satellites into polar Sun Synchronous Orbit (SSO) on September 26, 2016 from SDSC SHAR Sriharikota. Co-passenger satellites are ALSAT-1B, ALSAT-2B, ALSAT-1N from Algeria, NLS-19 from Canada and Pathfinder-1 from USA as well as two satellites PRATHAM from IIT Bombay and PISAT from PES University, Bengaluru.
- India's latest communication satellite, GSAT-18 was inducted into the INSAT / GSAT system on October 06, 2016 from Kourou, French Guiana by Ariane-5 VA-231. Weighing 3,404 kg at lift-off, GSAT-18 carries 48 communication transponders to provide services in Normal C-band, Upper Extended C-band and Ku-bands of the frequency spectrum along with a Ku-band beacon for accurately pointing ground antennas towards the satellite.
- In its 38<sup>th</sup> flight (PSLV-C36), ISRO's Polar Satellite Launch Vehicle successfully launches 1,235 kg Resourcesat-2A Satellite on December 07, 2016 from Satish Dhawan Space Centre SHAR, Sriharikota. This is the 37<sup>th</sup> consecutively successful mission of PSLV.



## Acronyms

AAI	:	Airports Authority of India
ABPP	:	Air Breathing Propulsion Project
ACL	:	Antrix Corporation Limited
ADC	:	Analog-to-Digital Converter
ADCOS	:	Advisory Committee for Space Science
AFTN	:	Aeronautical Fixed Telecommunication Network
AICIL	:	Agricultural Insurance Company of India Ltd
AIR	:	All India Radio
ALIMCO	:	Artificial Limbs Manufacturing Corporation of India
AO	:	Announcement of Opportunity
APEP	:	Ammonium Perchlorate Experimental Plant
APIOs	:	Assistant Public Information Officers
APXS	:	Alpha Particle X-ray Spectrometer
ARFI	:	Aerosol Radiative Forcing over India
ARG	:	Automatic Rain Gauge
ASC	:	AstroSat Support Cell
ASCI	:	Administrative Staff College of India
ASDM	:	Aerial Services & Digital Mapping
ASPEX	:	Aditya Solar wind Particle Experiment
ATCTM	:	Atmospheric Trace Gases Chemistry and Transport Modeling
ATV	:	Advanced Technology Vehicle
AVIRIS-NG	:	Advanced Visible and Infrared Imaging Spectrometer-Next Generation
AWiFS	:	Advanced Wide Field Sensor
AWS	:	Automatic Weather Stations
BCs	:	Boundary Conditions
BDR	:	Baseline Design Review
BIEC	:	Bengaluru International Exhibition Centre
BSX	:	Bengaluru Space Expo
CA-CFAR	:	Cell Averaging Constant False Alarm Rate



CBM-Z	:	Carbon-Bond Mechanism version Z
CCD	:	Charge Coupled Device
CEJ	:	Equatorial Counter Electrojet
CES	:	Crew Escape System
CFT	:	Cold Flow Test
CHAMAN	:	Coordinated programme on Horticulture Assessment & Management using Geoinformatics
CII	:	Confederation of Indian Industry
CM	:	Crew Module
CME	:	Continuing Medical Education
COPLLOT	:	Committee on Papers Laid on the Table
COWAA	:	Computerised Working in Administrative Areas
CPCS	:	Cabin Pressure Control System
CPIOs	:	Central Public Information Officers
CRS	:	Coarse Resolution ScanSAR
CSR	:	Corporate Social Responsibility
CSSTE-AP	:	Centre for Space Science and Technology Education in Asia and the Pacific
CUS	:	Cryogenic Upper Stage
CWDS	:	Cyclone Warning Dissemination System
CZTI	:	Cadmium Zinc Telluride Imager
DC	:	Deep Convective
DECU	:	Development and Educational Communication Unit
DEM	:	Digital Elevation Models
DGCA	:	Directorate General of Civil Aviation
DLA	:	Dual Launch Adaptor
DM	:	Dark Matter
DMA	:	Delhi Management Association
DMS	:	Disaster Management Support
DOA	:	Diocetyl Adipate
DOI	:	Digital Object Identifiers
DoLR	:	Department of Land Resources



DOS	:	Department of Space
DPT	:	Differential Pressure Transducers
DRT	:	Data Relay Transponder
DSC	:	Decision Support Centre
DSI	:	Drought Severity Index
DSNG	:	Digital Satellite News Gathering
DSPTs	:	Digital Satellite Phone Terminals
DSRQ	:	Directorate of Systems Reliability and Quality
DTH	:	Direct-To-Home
DWDS	:	Disaster Warning Dissemination Systems
ECLSS	:	Environmental Control and Life Support System
ECVs	:	Essential Climate Variables
EO	:	Earth Observation
EPRIS	:	Empowering Panchayati Raj Institutions Spatially
FEAST	:	Finite Element Analysis of Structures
FOV	:	Field of View
FRS	:	Fine Resolution Stripmap
FTP	:	File Transfer Protocol
GAGAN	:	GPS Aided GEO Augmented Navigation
GALEX	:	Galaxy Evolution Explorer
GCP	:	Ground Control Points
GEO	:	Geo-stationary Earth Orbit
GEOS-Chem	:	Goddard Earth Observation System Chemical
GFS	:	Global Forecasting System
GIS	:	Geographical Information System
GISAT	:	Geo Imaging Satellite
GMRT	:	Giant Metrewave Radio Telescope
GRBs	:	Gamma Ray Bursts
GSAT	:	Geo Synchronous Satellite
GSLV	:	Geosynchronous Satellite Launch Vehicle
GTO	:	Geosynchronous Transfer Orbit



HBCSE	:	Homi Bhabha Centre for Science Education
I&CAD	:	Irrigation and CAD
IAOP	:	Indian Astronomy Olympiad Programme
ICC	:	INSAT Coordination Committee
ICD	:	Interface Control Document
ICT	:	Information & Communication Technology
IGBP	:	ISRO Geosphere Biosphere Programme
IGS	:	International Ground Stations
IIRS	:	Indian Institute of Remote Sensing
IISc	:	Indian Institute of Science
IIST	:	Indian Institute of Space Science and Technology
IISU	:	ISRO Inertial Systems Unit
IITs	:	Indian Institute of Technologies
IMD	:	India Meteorological Department
IMDPS	:	INSAT Meteorological Data Processing System
IMG	:	Inter-Ministerial Group
IMGEOS	:	Integrated Multi mission Ground segment for Earth Observation Satellites
IMO	:	International Maritime Organisation
INC	:	IRNSS Navigation Centre
INCOSPAR	:	Indian National Committee for Space Research
INLUS	:	Indian Navigation Land Uplink Stations
INMCC	:	Indian Mission Control Centre
INRES	:	Indian Reference Stations
INSAT	:	Indian National Satellite
IPAB	:	Integrated Product Assurance Board
IPR	:	Intellectual Property Rights
IPRC	:	ISRO Propulsion Complex
IRCDR	:	IRNSS CDMA Ranging Stations
IRIMS	:	IRNSS Range and Integrity Monitoring Stations
IRNSS	:	Indian Regional Navigation Satellite System
IRNWT	:	IRNSS Network Timing Facility



IRSCF	:	IRNSS Spacecraft Control Facility
ISAC	:	ISRO Satellite Centre
ISEA	:	Indian Scientific Expedition to Antarctica
ISITE	:	ISRO Satellite Integration and Test Establishment
ISRO	:	Indian Space Research Organisation
ISTRAC	:	ISRO Telemetry Tracking and Command Network
JHSS	:	Sanyukt (Joint) Hindi Salahkar Samiti
KaRA	:	Ka-Band Radio Altimeter
kbps	:	kilobits per second
LAPT	:	Lander Actuator Performance Test
LAXPC	:	Large Area X-ray Proportional Counter
LEO	:	Low Earth Orbit
LEOS	:	Laboratory for Electro-Optics Systems
LIRAP	:	Laser Inertial Reference & Accelerometer Package
LIS	:	Land Information System
LOX	:	Liquid Oxygen
LPDC	:	Lander Pattern Detection Camera
LPFT	:	Low Pressure Fuel Turbo
LPOT	:	Low Pressure Oxidiser Turbo
LPSC	:	Liquid Propulsion Systems Centre
LSPT	:	Lander Sensor Performance Test
LST	:	Land Surface Temperature
LULC	:	Land Use Land Cover
LUTs	:	Local User Terminals
M & E	:	Monitoring & Evaluation
mbps	:	megabits per seconds
MCF	:	Master Control Facility
MCNC	:	Marine Carbon Nitrogen Cycles
MIP	:	Moon Impact Probe
MIS	:	Management Information System
MNREGA	:	Mahatma Gandhi National Rural Employment Guarantee Act



MOM	:	Mars Orbiter Mission
MOP	:	Main Oxidiser Pump
MoSJ&E	:	Ministry of Social Justice & Empowerment
MOTR	:	Multi-Object Tracking Radar
MOX	:	Mission Operations Complex
MPW	:	Multi-Product Wafer
MRCCs	:	Maritime Rescue Coordination Centres
MRS	:	Medium Resolution ScanSAR
MSC	:	Maritime Safety Committee
MSDE	:	Ministry of Skill Development & Entrepreneurship
NARL	:	National Atmospheric Research Laboratory
NCEP	:	National Centre for Environmental Prediction
NCP	:	National Carbon Project
NDEM	:	National Database for Emergency Management
NDRF	:	National Disaster Response Force
NDVI	:	Normalised Difference Vegetation Index
NEC	:	North Eastern Council
NER	:	North Eastern Region
NE-SAC	:	North Eastern-Space Applications Centre
NHN	:	Nickel Hydrazine Nitrate
NIAS	:	National Institute of Advanced Studies
NICES	:	National Information system for Climate and Environment Studies
NOBLE	:	Network of Observatories for Boundary Layer Experiments
NPP	:	Net Primary Productivity
NRSC	:	National Remote Sensing Centre
NSSS	:	National Space Science Symposium
OCM	:	Ocean Colour Monitor
OGDRs	:	Operational Geophysical Records
OLI	:	Operational Land Imager
OLICs	:	Official Language Implementation Committees
OPO	:	Optical Parametric Oscillator



OSCAT	:	Oceansat-2 Scatterometer
OS-CFAR	:	Ordered Statistics CFAR
PC-NNRMS	:	Planning Committee on National Natural Resources Management System
PDMS	:	Polydimethylsilane
PDR	:	Preliminary Design Review
PFA	:	Post Flight Analysis
PHMS	:	Personal Hygiene Management System
PI	:	Principal Investigators
PLANEX	:	Planetary Exploration
POLIX	:	Polarimeter Instrument in X-rays
PRL	:	Physical Research Laboratory
PSLV	:	Polar Satellite Launch Vehicle
PSP	:	Pre-Signalised Points
PSTN	:	Public Switched Telephone Network
QPOs	:	Quasi Periodic Oscillations
R&D	:	Research & Development
RAWEX	:	Regional Aerosol Warming Experiment
RCCs	:	Rescue Coordination Centres
RESPOND	:	Research Sponsored
RLV-TD	:	Reusable Launch Vehicle-Technology Demonstrator
RN	:	Radio Networking
ROTs	:	Receive Only Terminals
RoU	:	Right of Usage
RRI	:	Raman Research Institute
RRSCs	:	Regional Remote Sensing Centres
RS	:	Restricted Service
RTI	:	Right To Information
RXTE	:	Rossi X-ray Timing Explorer
SAC	:	Space Applications Centre
SAP	:	State Action Plan
SAR	:	Synthetic Aperture Radar



SAS	:	Surface Active Substances
SAS&R	:	Satellite Aided Search and Rescue
SATNAV	:	Satellite Navigation
SBAS	:	Satellite Based Augmentation System
SCAT	:	Semicryo flow control Components Assembly and Test
SCES	:	Satellite Control Earth Stations
SCFT	:	Semi-cryogenic Cold Flow Test facility
SCL	:	Semi-Conductor Laboratory
SCPD	:	Soil Carbon Pools and Dynamics
SDLP	:	Space-based Distance Learning Programme
SDM	:	System Demonstration Module
SDSC	:	Satish Dhawan Space Centre
SIS	:	Signal-In-Space
SMA	:	Shape Memory Alloy
SMART	:	Satellite Meteorology and Oceanography Research and Training
SNR	:	Signal-to-Noise Ratio
SPL	:	Space Physics Laboratory
SPPU	:	Savitribai Phule Pune University
SPS	:	Standard Positioning Service
SRSAC	:	State Remote Sensing Application Centre
SSM	:	Scanning Sky Monitor
SSP	:	Space Studies Programme
SSPA	:	Solid State Power Amplifier
SSPO	:	Sun Synchronous Polar Orbit
SSTM	:	Sea Surface Temperature Monitor
STC	:	Space Technology Cells
STFS	:	Standard Time and Frequency Signal
STPs	:	Structured Training Programmes
Sub-GTO	:	Sub-Geosynchronous Transfer Orbit
SUIT	:	Solar Ultraviolet Imaging Telescope
SVAB	:	Second Vehicle Assembly Building



SXT	:	Soft X-ray Telescope
TDP	:	Technology Development Programmes
TEC	:	Total Electron Content
TERLS	:	Thumba Equatorial Rocket Launching Station
THCS	:	Temperature and Humidity Control System
TIRS	:	Thermal Infrared Sensors
TM-CFAR	:	Trimmed Mean CFAR
TOSS	:	Transfer Orbit Support Service
TTC	:	Telemetry, Tracking and Command
TWRIS	:	Telangana Water Resources Information System
UP	:	Utilisation Program
UT	:	University of Twente
UVIT	:	Ultra Violet Imaging Telescope
VEDAS	:	Visualisation of Earth Observation Data and Archival System
VELC	:	Visible Emission Line Coronagraph
VER	:	Volume Emission Rate
VHRR	:	Very High Resolution Radiometer
VLSI	:	Very Large Scale Integrated circuit
VSAT	:	Very Small Aperture Terminal
VSSC	:	Vikram Sarabhai Space Centre
WV	:	Water Vapour
XPoSat	:	X-ray Polarimeter Satellite
XSM	:	Solar X-ray Monitor



IRNSS-1F



IRNSS-1G



CARTOSAT-2 SERIES



INSAT-3DR



SCATSAT-1



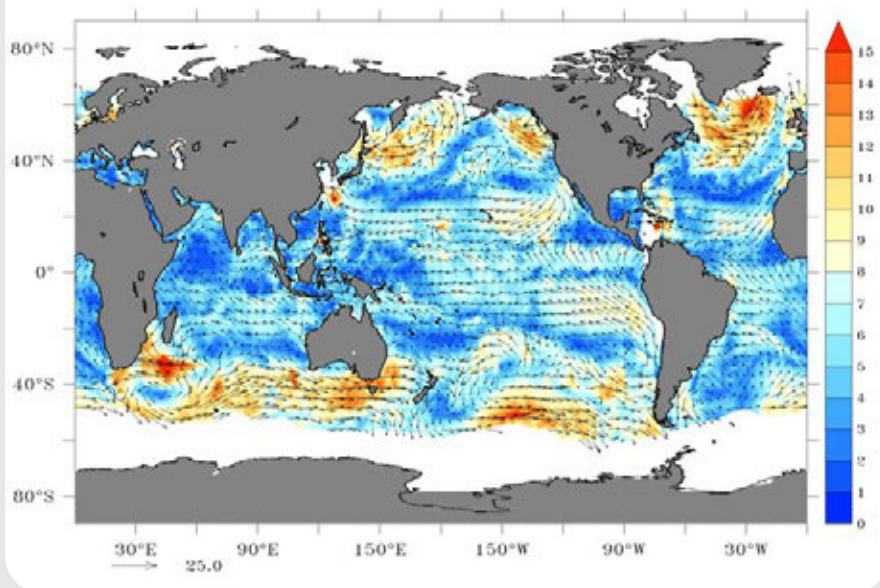
GSAT-18



RESOURCESAT-2A



SCATSAT-1 Winds (m / s) Global Coverage - October 03 - 04, 2016



RLV-TD



SCRAMJET



PSLV-C32



PSLV-C33



PSLV-C34



GSLV-FO5



PSLV-C35



PSLV-C36

